A N N U A L   R E P O R T

1961

U. S. WATER CONSERVATION LABORATORY
Southwest Branch
Soil and Water Conservation Research Division
Agricultural Research Service
United States Department of Agriculture
Tempe, Arizona

ADMINISTRATIVELY CONFIDENTIAL

LABORATORY STAFF

Professional:

Dr. H. Bouwer, Research Agricultural Engineer
Mr. K. J. Brust, Agricultural Engineer
Dr. W. L. Ehrler, Plant Physiologist
Mr. L. J. Erie, Research Agricultural Engineer
Mr. G. W. Frasier, Agricultural Engineer
Dr. L. J. Fritschen, Research Soil Scientist
Dr. R. D. Jackson, Soil Scientist
Mr. C. L. Jenson, Agricultural Engineer
Mr. L. E. Myers, Agricultural Engineer - Director
Dr. F. S. Nakayama, Research Chemist
Mr. R. J. Reginato, Soil Scientist
Mr. R. C. Rice, Agricultural Engineer
Dr. C. H. M. van Bavel, Research Soil Scientist

Research Assistants:

R. M. Bula, Hydraulic Engineering Aid
E. J. Durban, Engineering Aid
O. F. French, Hydraulic Engineering Technician
J. R. Griggs, Physicial Science Technician
J. M. Hernandez, Laborer
G. L. Jefferies, Physicial Science Aid
L. E. Lisonbee, Physicial Science Aid
J. L. MacIntyre, Physicial Science Technician
J. M. R. Martinez, Laborer
W. C. McDonnell, Agricultural Aid
J. B. Miller, Physicial Science Technician
K. G. Mullins, Physicial Science Aid
B. A. Rasnick, Physicial Science Technician
W. E. Reeves, Physicial Science Aid
A. L. Sandecki, Physicial Science Aid
B. W. Tilden, Agricultural Aid

Administrative, Clerical & Maintenance:

O. J. Abeyta, Laborer
E. D. Bell, General Machinist
E. E. De La Rosa, Janitor
E. D. Escarcega, Engineering Draftsman
A. V. Figueroa, Laborer
D. S. Fry, Clerk-Stenographer
C. E. Hansen, Clerk-Stenographer
C. G. Hiesel, Machinist Helper

Administrative, Clerical, and Maintenance:

N. A. Johnson, Clerk
R. C. Klapper, Refrigeration and Air Conditioning Mechanic
R. S. Miller, Clerk-Stenographer
M. E. Olson, Clerk-Stenographer
M. M. Phillips, Librarian Assistant
M. A. Seiler, Clerk-Stenographer

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CHANGES IN PERSONNEL

The Laboratory staff has been strengthened during 1961 by the addition of nineteen new members. They are as follows:

Mr. O. J. Abeyta, Laborer
Mr. R. M. Bula, Hydraulic Engineering Aid
Mr. E. J. Durban, Engineering Aid
Mr. E. D. Escarcega, Engineering Draftsman
Mr. J. R. Griggs, Physical Science Technician
Miss C. E. Hansen, Clerk-Stenographer
Mr. J. M. Hernandez, Laborer
Mr. C. G. Hiesel, Machinist Helper
Mr. G. L. Jefferies, Physical Science Aid
Mr. L. E. Lisonbee, Physical Science Aid
Mr. J. M. R. Martinez, Laborer
Mr. W. C. McDonnell, Agricultural Aid
Mr. J. B. Miller, Physical Science Technician
Mr. K. G. Mullins, Physical Science Aid
Mrs. M. M. Phillips, Librarian Assistant
Mr. W. E. Reeves, Physical Science Aid
Mr. A. L. Sandecki, Physical Science Aid
Miss M. A. Seiler, Clerk-Stenographer
Mr. B. W. Tilden, Agricultural Aid

Also during 1961 there were eight resignations and one transfer. They are as follows:

Mrs. R. C. Berthold, Clerk-Stenographer
Mr. J. W. Evans, Physical Science Aid
Mr. C. W. Kohli, Engineering Technician
Mr. R. C. McClain, Engineering Draftsman
Mr. R. L. Mendez, Laborer
Mr. F. E. Osuna, Machinist Helper
Mr. C. F. Redman, Agricultural Aid
Mr. G. B. Smith, Agricultural Aid
Mrs. A. M. Richard (Schreyer), Clerk-Stenographer - transferred to the Department of the Navy at Pomona, California.

The Laboratory staff is now essentially at full strength with one or two exceptions.

TITLE: CALIBRATION OF RESISTANCE NETWORK ON ELECTRICAL ANALOG

LINE PROJECT: SWC 4-gG1

INTRODUCTION:

Prior to solving flow systems on the resistance network analog, the network arrangement used in the analyses must be checked for errors in calculating and setting resistance values. The most effective way to do this is to impose on the network uniform one-dimensional flow and to compare measured flow rates and potentials with calculated values. An example of such a calibration will be presented for the network arrangement which is to be used in recently initiated analog studies to evaluate the effect of ground-water table, water depth in canal, and bottom-conductivity conditions on seepage and distribution of seepage from canals.

PROCEDURE:

The network arrangement used in the analyses is shown in figure 1. To impose one-dimensional uniform flow on this system, the "canal was filled with soil" so as to lend the flow system a rectangular geometry. Electrodes were then placed along the surface and the bottom of the network and a potential difference between the electrodes was applied to simulate vertically downward flow. The procedure was repeated with vertical electrodes on the left and on the right side of the system to simulate one-dimensional horizontal flow.

The unit resistance of the network was 200 ohms, which corresponds to an hydraulic conductivity of 1/200 units. Because of the non-uniform mesh sizes, actual resistance values on the analog board ranged from

33 to 3200 ohms. Diagonal resistors were used in the transition to subdivided meshes.

RESULTS AND DISCUSSION:

Vertical flow. The line of zero-resistances at 80 length units from the line of symmetry, which represents infinity or open boundary conditions, was removed and electrodes were installed connecting the network points at the top and at the bottom of the network, respectively. The dimension of the flow system normal to the flow direction was thus half way between the two last lines of resistors, or 76 length units. Thus, the rectangular flow system was 76 length units wide and 100 length units deep. Imposing a difference of 1.00 potential units between the electrodes at the top and at the bottom of the system should, according to the Darcy equation, yield a flow of $\frac{1}{200} \times 76 \times \frac{1}{100} = 0.0038$ flow units. The measured flow was 0.00379 amps, yielding an error of only 0.26%. The measured potentials at the network nodes were all within 1% of the calculated values, and most potentials were within 0.5%.

Horizontal flow. To obtain horizontal one-dimensional flow, the zero-resistances in the line 100 network units below the surface were disconnected, so that the boundary of the flow system was half way between 68 and 100 units, or 84 units. The dimension in the direction of flow is 80 length units, so that 0.8 potential units difference between the electrodes at the right and at the left of the system should yield a flow of $\frac{1}{200} \times 84 \times \frac{0.8}{80} = 0.0042$ flow units. The measured flow was 0.00422 amps, yielding an error of only 0.48%.

Almost all potentials at the nodes were within 0.5% of the calculated values and a few were within 1%.

SUMMARY AND CONCLUSIONS:

The accuracy of a network arrangement was tested for a network to be used in an analysis of factors controlling canal seepage. The network was temporarily supplemented with resistors in the simulated canal so as to form a system of rectangular geometry. Measured flow rates and potentials were then compared with calculated flow rates and potentials for one-dimensional uniform vertical flow and horizontal flow, respectively. The results showed, that the overall accuracy of the network instrumentation was within 0.5%. This is more than sufficient for a resistance network analog to be used in water management research. The accuracy of the network as a whole is much better than the accuracy of the individual resistors, which were calibrated by hand.

PERSONNEL: H. Bouwer

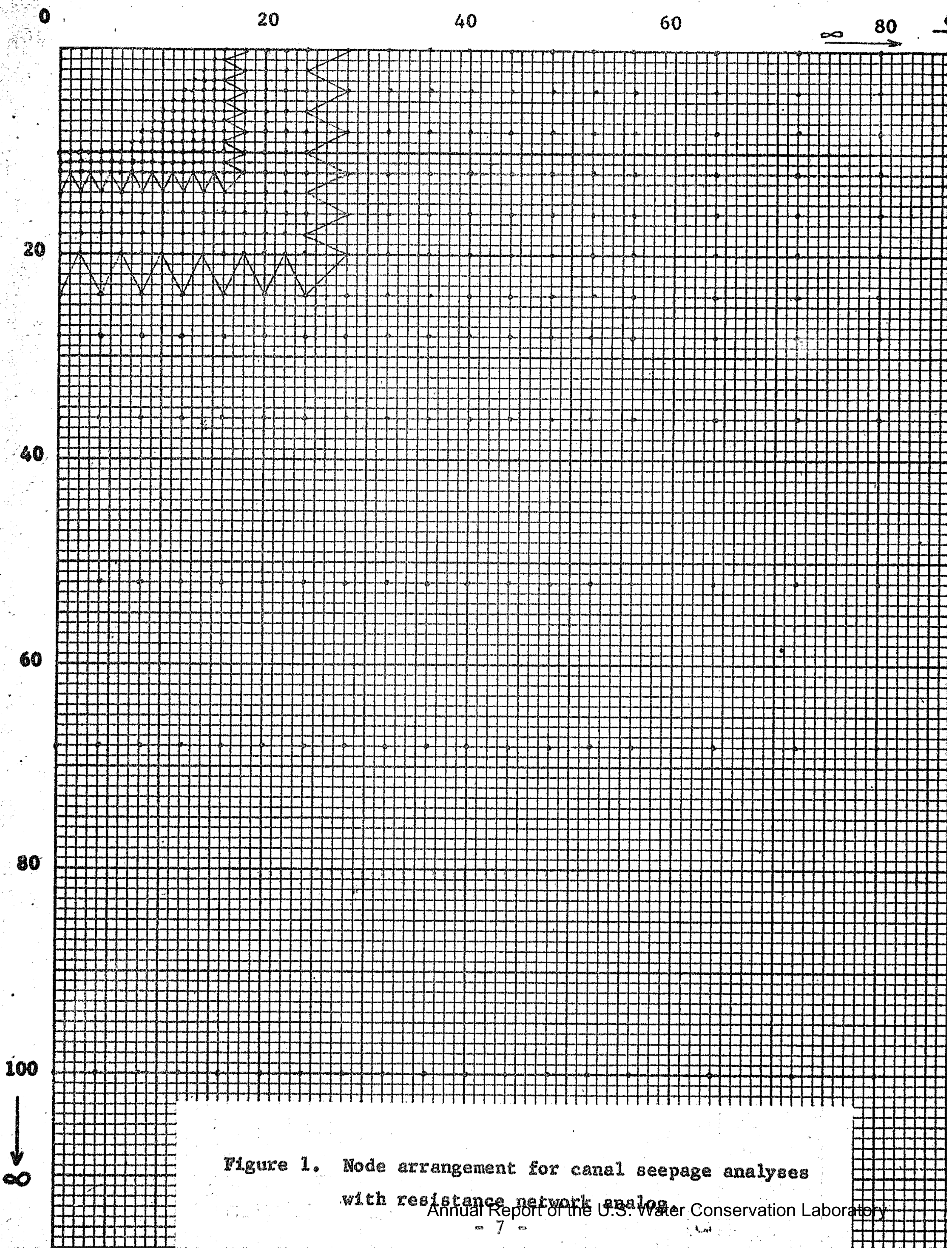


Figure 1. Node arrangement for canal seepage analyses with resistance network analog.

TITLE: HEAD ENVIRONMENT OF SEEPAGE METERS IN FLOWING WATER

LINE PROJECT: SWC 4-gG1 CODE: Ariz.-WCL-4

INTRODUCTION:

Seepage measurements with seepage cups are based on the outflow from the cup when the pressure head inside the cup equals that of the free water in the canal. This applies to the equal-head technique as well as to the falling-head technique. For the falling-head technique, the pressure head outside the seepage cup is used as reference level (17). Normally, the pressure head outside the seepage cup is taken as the free water surface in the canal above the seepage cup. In flowing water, however, stagnation at the upstream face of the seepage cup and a tendency for separation at the downstream face, may cause the average "local" pressure head of the seepage cup to differ from the free water surface. Using the terminology of a previous paper (17), seepage measurement with cup-type devices should be based on that pressure head inside the cup whereby the leakage flow is zero. In still water, this head is obviously the free water level. In flowing water, however, velocity distortion may cause the pressure head of zero leakage to be not the same as the free water surface above the seepage cup.

Model studies were carried out in a laboratory flume to determine the effect of the flow distortion on the pressure environment of the seepage cup. The study showed that velocity caused the average pressure head around the seepage cup to be somewhat below the free water surface. Correction factors to convert the free water surface to the zero-leakage head for seepage measurement with seepage cups were developed.

With cup-type seepage meters, canal seepage is measured from a still body of water whereas the natural seepage takes place while the water in the canal is moving. For correct interpretation of the results of seepage meter tests, therefore, it is necessary to know whether velocity has a direct effect on seepage rate. Contradictory opinions regarding this effect exist and conclusive data are to our knowledge not available. Model studies, carried out in the same laboratory flume as the head-environment studies of seepage meters, showed that velocity had no direct effect on seepage rates. Thus, measuring seepage from flowing canals by means of still water bodies, such as inside seepage cups or ponded sections, is in principle correct.

PROCEDURE:

A. Head environment of seepage meters.

The hydraulic flume, the test section, and the procedure used in the head-environment study for seepage meters are described in the Annual Report 1960. For convenience, the nomenclature will be repeated here.

d = depth of penetration of seepage cup in canal bottom

D = depth of water in canal

h = zero-leakage pressure head in seepage cup

Δh = vertical distance of zero-leakage head below free water surface, i.e., D-h, or correction factor to be deducted from free water surface to obtain reference level for seepage measurement

R_c = radius of seepage meter cup

V = velocity of approach (undisturbed velocity in bottom at seepage cup location)

W = bottom width of canal

B. Effect of velocity on seepage.

The direct effect of velocity on seepage was studied in the same test section in the hydraulic flume as the studies on head-environment of seepage cups. The test section consisted of a water-tight box of the same width as the flume. The box was 16 inches deep and four feet long. The open top of the box was at the same elevation as the bottom of the flume. A layer of gravel drained by perforated tubing was placed in the bottom of the box which was then filled with uniform sand (mean particle diameter 0.5 mm.) with the sand surface flush with the bottom of the flume. The sand surface was stabilized with a plastic resin to avoid erosion. It was found that 20 parts of sand and one part of resin by weight yielded sufficient solidification and yet reduced permeability of the sand by less than 30 per cent. The drainage system for the box was connected by flexible, transparent tubing to a discharge device which was essentially a small constant level reservoir which could be adjusted in elevation. Piezometers were installed in the gravel to indicate the static pressure head at the bottom of the sand in the box. Measurements were first made to determine whether velocity had any effect on static pressure conditions within the box. This was done by comparing static pressure heads measured at the bottom of the box with the free water surface in the channel with the drainage system closed (zero seepage) for a range of velocities. It was found that velocity had no influence on static pressures within the box.

Seepage rates were determined for different velocities and different seepage intensities. The latter were expressed as the difference between the elevation of the water surface in the flume and the elevation of the water surface in the piezometers in the gravel at the bottom of the box. Tests were always started and concluded with ponded water to ascertain whether or not the sand characteristics had changed during a series of tests.

After completion of the tests with sand as the channel bottom, the top 3 inches of the sand were replaced by one-half-inch gravel which was also solidified with plastic resin. The tests were then repeated with gravel serving as the channel bottom in the test section.

RESULTS AND DISCUSSION:

A. Head environment of seepage meters.

As discussed in the annual report 1960, the results were expressed in terms of $\Delta h(V^2/2g)$. The results of all tests for the three cup sizes employed in the model study were shown in terms of the arbitrarily selected dimensionless parameter $\frac{\Delta h}{V^2/2g}\sqrt{\frac{W}{2R_c}}$ as a function of $\frac{D}{W}$ for various $\frac{d}{R_c}$ - values (figure 1). The possibility of generalization of the data into one graph suggests the absence of scale effects and permits extension of the data to prototype dimensions.

Extrapolation of the curves in figure 1 shows that when $\frac{d}{R_c}$ approaches a value of one, Δh approaches a value of zero. At this condition, the flow between the region of pressure increase and pressure reduction around the seepage cup must mainly occur in the bottom material around the side of the cup and not under the cup. The pressure inside the cup is, therefore, equal to the pressure in the bottom material that is unaffected by the pressure distortion. In the absence of seepage, this pressure is obviously the free water surface. Therefore, Δh becomes essentially zero when $\frac{d}{R_c}$ equals or exceeds a value of one. The curves in figure 1 also show that increasing the water depth (increasing $\frac{D}{W}$) tends to lower Δh, but that the effect of D on Δh becomes very small for $\frac{D}{W}$ - values exceeding 0.7. This effect can be explained from a standpoint of constricting area and resulting stagnation pressures. At small D, the constriction due to the seepage cup is relatively large, so that increasing D will decrease Δh. The effect of D on Δh, however, can be expected to cease when D is large. Thus, the effect of D is most pronounced when D is relatively small.

To estimate Δh for actual conditions, one must know the approximate bottom velocity, the water depth, the bottom width of the channel and the diameter and depth of penetration of the seepage cup. The value of the term

$$\frac{\Delta h}{V^2/2g}\sqrt{\frac{W}{2R_c}}$$

is then determined from figure 1 after which Δh, which is the only unknown in this term, can be computed. The appropriate reference pressure head for seepage measurement is then a distance Δh below the free water surface. For the flume in which the model studies were performed, the bottom velocity ranged from 80% of the average velocity for the lower velocities to 90% of the average velocity for the higher velocities.

To facilitate estimating Δh, a table has been prepared from which Δh can be directly evaluated, or interpolated, for various values of $\frac{d}{R_c}$, $\frac{2R_c}{W}$, $\frac{D}{W}$, and V (Table 1).

In order to determine under which conditions correction for velocity-induced pressure differences is necessary, an analysis will be made of the error in seepage measurement that would occur if no correction for velocity-induced pressure differentials was made. According to a paper in press (26), the error can be calculated as

$$E = \frac{F_f \Delta h}{G\ R_c}\ 100$$

where E is the error in percent, F_f is a dimensionless parameter determined by the geometry of the seepage cup installation (graphs showing F_f in relation to $\frac{d}{R_c}$ and the depth to impermeable or much more permeable material are presented in (22)), and G is the seepage gradient (seepage rate)/(hydraulic conductivity).

The factor F_f will generally fall in the range from 1.5 to 2. Taking a value of 1.8 for F_f, and assuming R_c is 7 inches and Δh is 0.1 inch, E can be expressed as $E = \frac{2.6\%}{G}$. Thus, for high seepage gradients of one half or more, the error tends to be small and the free water surface can be taken as reference level for seepage measurement. For relatively low seepage gradients, which may occur if the seepage cup is placed in material of higher conductivity than that of underlying soils, E can be considerable and correcting the free surface for velocity-induced pressure differences could be desirable. For instance, if G = 0.1, basing the seepage measurement on the uncorrected free water surface would cause an error of approximately 26% for the conditions applying to the above equation.

B. Effect of velocity on seepage.

A graph was constructed showing the seepage rate in cubic inches per minute as a function of the difference between the water surface and the tail pressure head for different velocities (figure 2). Even though the velocity was varied from 0 to almost 7 ft/sec, all points are on or scattered around a straight line. This shows that velocity has no measurable direct effect on seepage.

SUMMARY AND CONCLUSIONS:

The effect of the velocity pattern distortion around a seepage cup on the local head environment of the cup and the direct effect of velocity in a canal on seepage rates were studied in a laboratory flume. Velocity distortion around the cup caused the everage head around the cup to be below the free water surface in the canal. Correction factors to convert the free water surface to the proper reference level for seepage measurement with cup-type devices were evaluated and expressed in the form of a graph and a table. It is shown that correcting the free water surface for velocity-induced pressure differences is only necessary in case of low seepage gradients. Velocity appeared to have no measurable direct effect on seepage, which indicates that evaluating seepage from normally flowing canals by means of still water bodies (seepage cups or ponding tests) is in principle correct.

PERSONNEL: H. Bouwer, L. E. Myers, R. C. Rice.

Table 1. Values of Δh in inches for various values of velocity, D/W, $2R_c/W$, and d/R_c.

		$2R_c/W = 0.1$				$2R_c/W = 0.2$				$2R_c/W = 0.3$				$2R_c/W = 0.4$				$2R_c/W = 0.5$			
	d/R_c	.10	.20	.40	.60	.10	.20	.40	.60	.10	.20	.40	.60	.10	.20	.40	.60	.10	.20	.40	.60
D/W	V ft/sec.																				
	1.0	.05	.03	.02	.01	.07	.05	.03	.02	.08	.06	.03	.02	.09	.07	.04	.03	.10	.07	.04	.03
	1.5	.11	.07	.04	.03	.15	.10	.06	.04	.18	.13	.08	.05	.21	.15	.09	.06	.23	.16	.10	.06
0.2	2.0	.19	.13	.08	.05	.26	.19	.11	.07	.32	.23	.14	.09	.37	.26	.16	.10	.42	.29	.18	.11
	2.5	.29	.20	.12	.08	.41	.29	.17	.11	.51	.35	.21	.13	.58	.41	.24	.15	.65	.46	.27	.17
	3.0	.42	.29	.18	.11	.59	.42	.25	.16	.73	.51	.31	.19	.84	.59	.35	.22	.94	.66	.39	.25
	1.0	.03	.02	.01	.01	.04	.03	.02	.01	.05	.04	.02	.01	.06	.04	.03	.02	.07	.05	.03	.02
	1.5	.07	.05	.03	.02	.09	.07	.04	.02	.11	.08	.05	.03	.13	.10	.06	.03	.15	.11	.07	.04
0.4	2.0	.12	.09	.05	.03	.17	.12	.08	.04	.20	.15	.09	.05	.23	.17	.11	.06	.26	.19	.12	.07
	2.5	.18	.14	.09	.05	.26	.19	.12	.07	.32	.23	.15	.08	.36	.27	.17	.09	.41	.30	.19	.10
	3.0	.26	.19	.12	.07	.37	.28	.17	.09	.46	.34	.21	.12	.52	.39	.24	.13	.59	.44	.27	.15
	1.0	.02	.02	.01	.01	.03	.02	.01	.01	.03	.03	.02	.01	.04	.03	.02	.01	.04	.03	.02	.01
	1.5	.04	.03	.02	.01	.06	.05	.03	.02	.08	.06	.04	.02	.09	.07	.04	.02	.10	.08	.05	.03
0.6	2.0	.08	.06	.04	.02	.11	.09	.05	.03	.14	.11	.07	.04	.16	.12	.07	.04	.17	.14	.08	.05
	2.5	.12	.10	.06	.03	.17	.13	.08	.05	.21	.17	.10	.06	.24	.19	.12	.06	.27	.21	.13	.07
	3.0	.18	.14	.08	.05	.25	.19	.12	.07	.30	.24	.15	.08	.35	.27	.17	.09	.39	.31	.19	.10
	1.0	.02	.01	.01	---	.02	.02	.01	.01	.03	.02	.02	.01	.03	.03	.02	.01	.04	.03	.02	.01
	1.5	.04	.03	.02	.01	.05	.04	.03	.01	.07	.05	.03	.02	.08	.06	.04	.02	.09	.07	.04	.02
0.8	2.0	.07	.05	.04	.02	.10	.08	.05	.03	.12	.09	.06	.03	.14	.11	.07	.04	.15	.12	.08	.04
	2.5	.11	.08	.05	.03	.15	.12	.08	.04	.19	.15	.09	.05	.21	.17	.11	.06	.24	.19	.12	.06
	3.0	.15	.12	.08	.04	.22	.17	.11	.06	.27	.21	.14	.07	.31	.24	.16	.08	.34	.27	.18	.09
	1.0	.02	.01	.01	---	.02	.02	.01	.01	.03	.02	.01	.01	.03	.03	.02	.01	.04	.03	.02	.01
	1.5	.04	.03	.02	.01	.05	.04	.03	.01	.06	.05	.03	.02	.07	.06	.04	.02	.08	.07	.04	.02
1.0	2.0	.07	.05	.03	.02	.09	.07	.05	.02	.11	.09	.06	.03	.13	.10	.07	.03	.15	.12	.07	.04
	2.5	.10	.08	.05	.03	.15	.11	.07	.04	.18	.14	.09	.05	.21	.16	.10	.05	.23	.18	.11	.06
	3.0	.15	.12	.07	.04	.21	.16	.10	.05	.26	.20	.13	.06	.30	.23	.15	.07	.33	.26	.16	.08

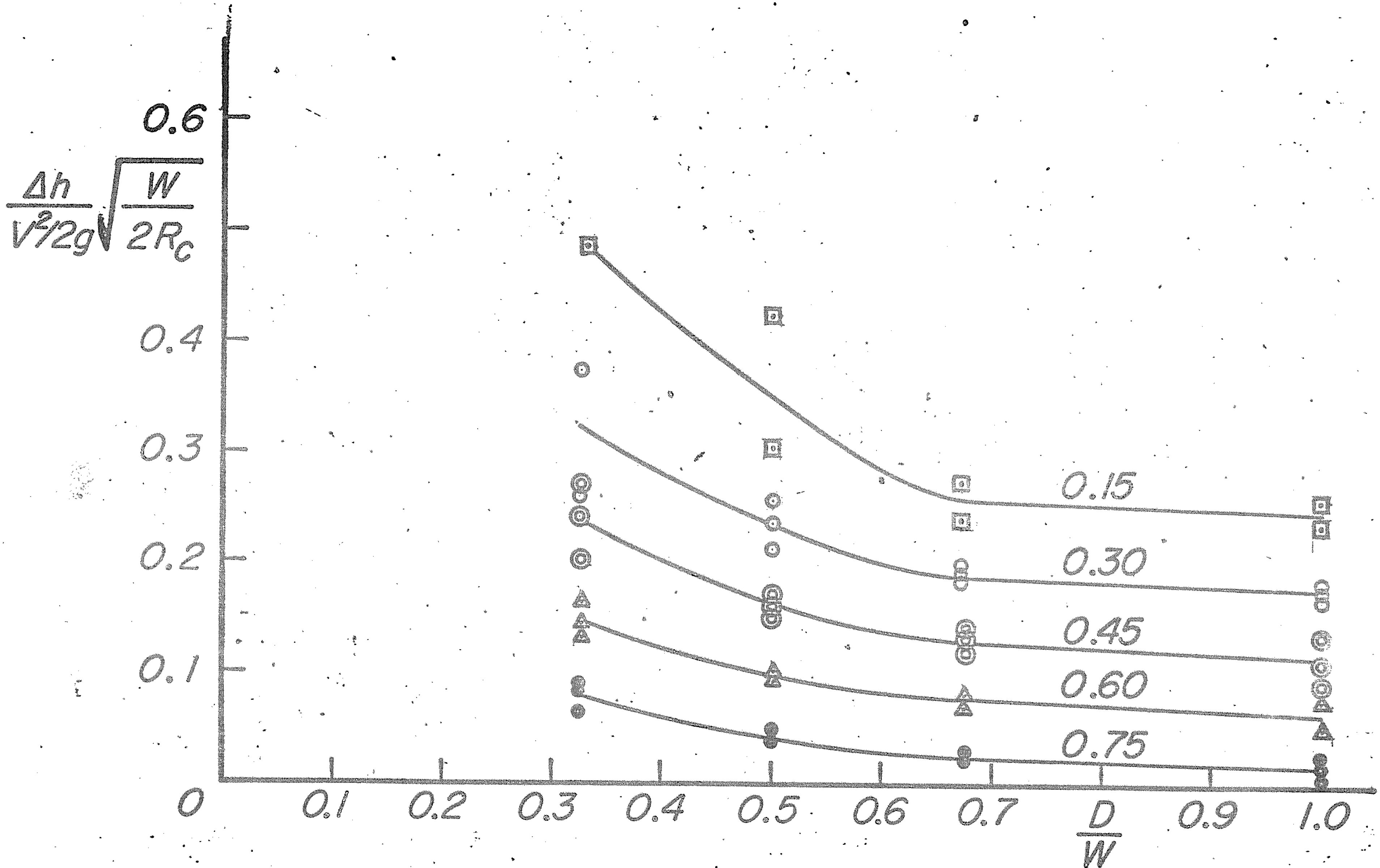


Figure 1. Test results for all cup models for various values of S/R_c [illegible]

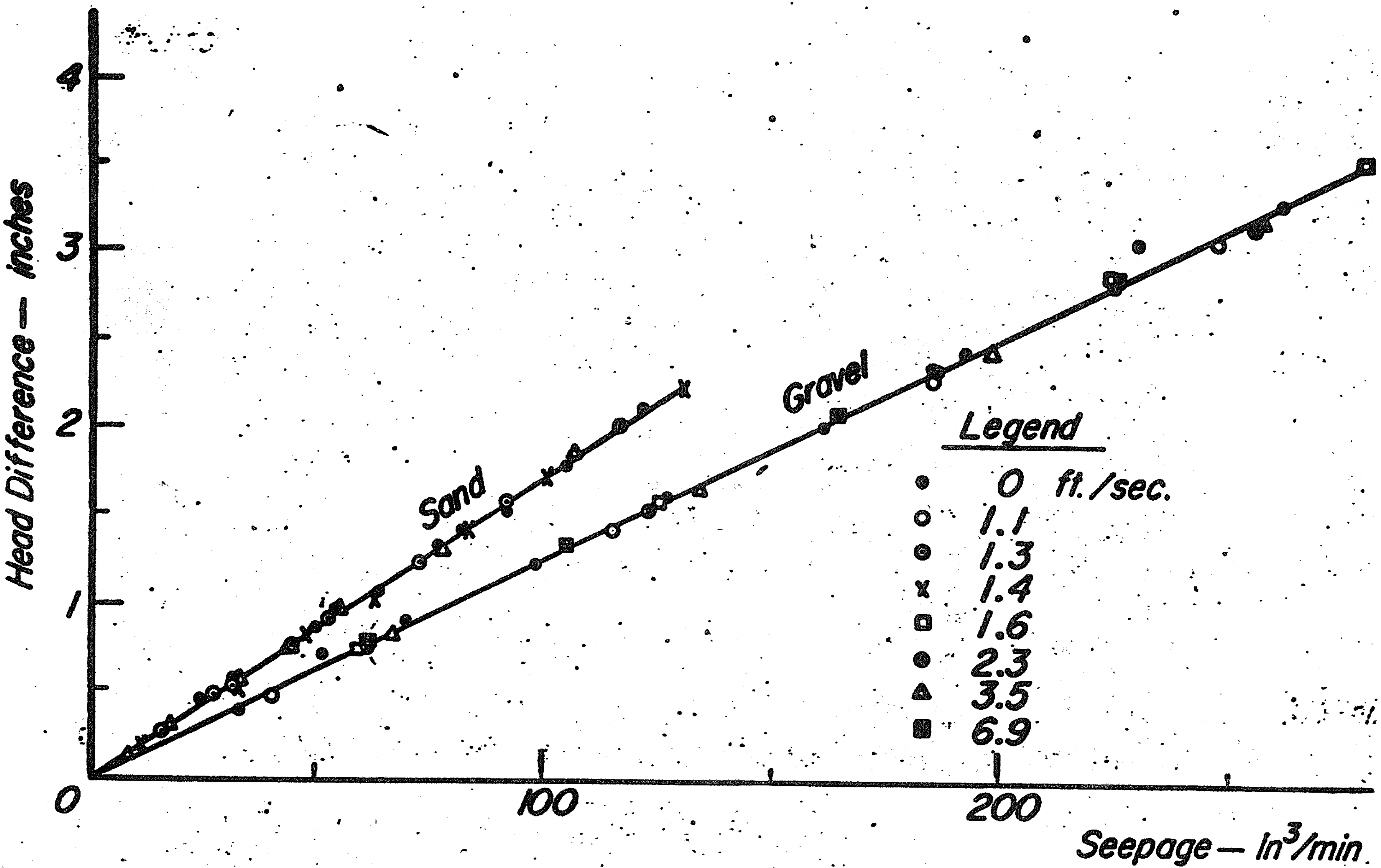


Figure 2. Seepage rates plotted against difference between water surface and "tail" pressure head for various velocities and two bottom materials (sand and gravel).

TITLE: SOIL TREATMENT TO REDUCE SEEPAGE LOSSES FROM CANALS AND PONDS

LINE PROJECT: SWC 4-gG 1 CODE NO.: Ariz.-WCL-8

INTRODUCTION:

See Annual Report for 1960.

PROCEDURE:

Same as reported in Annual Report for 1960 except where noted in discussion of materials.

RESULTS AND DISCUSSION:

The information presented here represents a preliminary progress report of partially completed tests which may be subject to change. For this reason the tested materials are identified by code numbers rather than by product name and manufacturer.

Material D-1

Material D-1 is the designation we have used for sodium phosphate materials including sodium tripolyphosphate as D-1a, sodium hexametaphosphate as D-1b, and tetrasodium pyrophosphate as D-1c, which can seal soils by dispersing the clay fraction. Laboratory measurements showed that our local soils, compacted dry into infiltration cylinders, could be readily sealed with these materials if the soil contained over 10 per cent clay. This was accomplished by applying the materials to the soil surface in a water solution with no mechanical mixing.

A field testing site was obtained in two ponds, each about one acre in area with an average depth of 8 feet, owned by Mr. John Randall, Pine, Arizona. The soil and water are described in Tables 2 and 3 respectively. The water is obtained from a nearby creek. Laboratory studies showed that D-1b (sodium hexametaphosphate) completely sealed the soil surface when applied at rates as low as 250 pounds per acre. Infiltration cylinder and seepage meter measurements made within the ponds showed untreated seepage and infiltration rates to average about 0.25 inches per hour. D-1b completely stopped infiltration when applied to the soil surface within the infiltration cylinders at a rate of 1000 pounds per acre. Water stage recorders were installed on the ponds and showed that the ponds went dry about 15 days after filling to a depth of 5 feet.

Material D-1b was dissolved in water, 100 pounds per 300 gallons, and sprayed on the soil surface in Pond 1 at a rate of 700 pounds of D-1b per acre. The water had to be heated before the D-1b would dissolve. No runoff of solution from the steep sides of the pond was experienced. Water was turned into the pond immediately after spraying was completed. The pond was dry 23 days after the pond was filled to a depth of 4.8 feet and the water turned off, indicating that the treatment had failed.

Failure of the treatment must be explained by differences between laboratory and field treatment conditions. Laboratory tests showed that heating the water to get the D-1b into solution does not reduce the effectiveness of the material. The soil was cracked at the time of spraying. It is our present belief that much of the spray solution went into the cracks and was not actually applied to the soil surface. This is currently under investigation.

Material H-1

Material H-1 was briefly discussed in the 1960 Annual Report. Depth of penetration into soil and the effect of drying were investigated during 1961.

Penetration of H-1 into soil was investigated with the control soil uniformly compacted into a 4.75 inch diameter, 60 inch long, transparent plastic tube. A constant head of 6 inches of water was maintained above the soil surface and the seepage rate was determined from effluent measurements. Hydraulic conductivity of soil layers at various depths was determined from the seepage rate and the head loss for these layers as measured with piezometers connected to a 20 tube photomanometer. The piezometer taps were hypodermic needles thrust through the tube walls into the center of the soil column to avoid wall effects. Columns were run at least 24 hours before treatment to obtain the hydraulic conductivity of the soil at various depths. Material H-1 was applied for 48 hours at a concentration of 1000 ppm in tap water. The treated water was removed and the run completed with plain tap water to obtain post-treatment hydraulic conductivity measurements. Untreated columns were run continuously to serve as checks. Typical changes in hydraulic conductivity are shown in Figure 3. These changes are considered to be due to the treatment with H-1 and indicate that the material penetrated into the soil to a depth of approximately 4 inches.

The influence of drying on H-1 was investigated in a cooperative ponding test in the main canal of the Maricopa County Municipal Water Conservation District No. 1, Beardsley, Arizona. This was a joint effort by the District, the Bureau of Reclamation and our Laboratory. One ponded section of the canal, in soil similar to the Beardsley soil described in Table 2, was used. Pre-treatment seepage rates were about 1.50 inches per hour as measured by the drop in the water surface. Material H-1 was added to the ponded canal water on February 3, 1961. Seepage dropped to 0.60 inches per hour on February 6. The canal was drained on February 7 and allowed to dry until April 17. Seepage on April 24 was 1.32 inches per hour. The canal was drained, allowed to dry and cleaned with a road grader. On June 15, the seepage was 1.44 inches per hour. Drying had obviously destroyed the effectiveness of the treatment.

Materials S-1, S-2, S-3 and S-4

These are experimental asphalt emulsions formulated to permit dispersion in water. They can be sprayed on the soil surface but are designed for addition to ponded water in canals and reservoirs. The dispersed asphalt plates out on the soil surface, with some penetration, to reduce seepage and to form a surface lining. Four basic formulations, designated as S-1, S-2, S-3 and S-4 were studied. Modifications are designated with a lower case letter such as S-1a, S-1b, and so on.

Field studies were conducted at four sites in the general Phoenix area and are designated as Beardsley, San Marcos, Lakin 1 and Lakin 2. Descriptions of the soil and water at these sites are presented in Tables 1, 2 and 3. The general textural description is: Beardsley - sandy loam; San Marcos - sandy clay loam; Lakin 1 - silty loam; Lakin 2 - silty sand.

Procedure:

Studies were conducted in permanent or temporary ditches divided into ponds by plastic or earth dams. Plastic was used initially but earth dams were later adopted to avoid any uncertainty of seepage under the plastic. The plastic dams shifted as the head changed on each side of the dams during tests. Unless otherwise stated the ditches were trapezoidal with a one-foot bottom width and 1 to 1 side slopes. Water was added to the ponds with pumps or siphons as appropriate to maintain a depth of 1.5 to 2.0 feet. Siphons were used to transfer water from upper to lower ponds prior to treatment. Six-inch diameter aluminum siphons, primed with a suction pump, proved very satisfactory for this purpose. Following treatment, water was added to individual ponds with pumps and hoses varying in size and capacity from 3/4-inch garden hose to 6-inch lay-flat butyl tubing. An automatic water distribution system was designed and performed well except when violent fluctuations in the supply canal occurred. Such fluctuations did occur unpredictably and the system could not be used. Seepage from the ponds was determined by measuring the drop in water surface elevations with hook gages or water stage recorders. Pre-treatment and post-treatment seepage measurements were made. The resulting asphalt film was checked visually for creep down sideslopes. Toughness, tackiness, thickness and penetration into soil was determined by rough field tests such as manual manipulation of film samples and observance of asphalt-soil cross-sections obtained with a pocket knife.

Results and Discussion:

Field study results are presented in chronological sequence.

February 21-27: The first field trial was conducted with material S-1b at the Beardsley site in an operating canal. Bottom width was 1.5 feet and side slopes were 1 to 1. A 200 foot length of the canal was divided into four 50 foot ponds with plastic dams. Water depths were maintained continuously at approximately 2 feet by adding water at intervals with a portable pump. Two check ponds were untreated and two ponds were treated by adding emulsion at the rate of 1/2 gallon per square yard of wetted perimeter. Emulsion was poured into the ponds and dispersed by diffusion and convection. No mechanical mixing was employed. Pre-treatment seepage rates varied from 1.65 to 4.10 inches per hour. Seepage rates in the untreated ponds decreased about 0.5 inch per hour during a 96 hour period following treatment. Seepage rates in the treated ponds were still in excess of 1.0 inch per hour 96 hours after treatment. Although seepage was reduced 40 to 60 per cent, the treatment was considered a failure.

July 13-17: Tests were conducted in standard 25-foot ponds at the San Marcos site to check the performance of materials S-1a and S-1b applied to a sandy clay loam soil at two different rates by ponding and spraying. Spray applications were made with a portable asphalt pump, gear type, and a Veejet 1/4U8030 nozzle at 40 psi. Test data are presented in Table 4. Treatments were replicated. The need for replication because of the variation in seepage rates for apparently identical ponds is shown in Figure 1. Seepage reduction by the ponding treatment was considerably less than expected. The soil cracked during treatment and ruptured the asphalt film. Spray application was not successful. Soil clods were not completely coated with asphalt and disintegrated when wetted, leaving numerous untreated spots in the ditch bed.

July 22-30: Chemical pre-treatment, spray, and double application treatments were tested at the San Marcos site. Test data are presented in Table 5. The chemical pre-treatment, added to the ponded water prior to addition of the emulsion, was intended to improve penetration of material S-1f into the soil but did not do so. Spray applications of S-1b resulted in a porous film which did not reduce seepage appreciably. The double, or repeated, applications of S-1b consisted of adding one-half the emulsion on one day and adding the remaining half the next day. It was intended that the second application would fill the soil cracks caused by the first application. Although the asphalt did penetrate into the cracks, even small hairline cracks, seepage reduction was not satisfactory. Some of the emulsion broke and was observed floating on the water surface.

July 30 - August 11: Materials S-2b, S-2f and S-1b were applied by ponding and spray at the San Marcos site as shown in Table 6. Material S-2b broke in the water and floated to the surface. Laboratory studies were immediately initiated and it was found that the "b" modification of all basic formulations broke when water temperatures exceeded 90^{o}F. This water temperature was exceeded in the San Marcos test ponds. The second half of the double applications was made with materials S-2a and S-2e. Reasonably good seepage reduction was obtained with some of the treatments despite the fact that the first half of the treatment had not performed properly. The spray treatment failed again due to partially coated soil clods which disintegrated when the sprayed ponds were filled with water.

August 9-11: Material S-2a was applied to the silty loam soils at the Lakin 1 site by ponding at different rates, both single and double applications, and by spraying. Test data are summarized in Table 7. The soil did not crack and there was no advantage in double treatments. Fair seepage reduction was obtained with all ponding treatments. Film thickness decreased with increased elevation above the ditch bottom. This had been previously observed in the San Marcos Tests. No appreciable penetration into the soil was observed.

Two of the spray treatments, applied to rough soil, failed. One spray application was made on smooth soil and produced a continuous film which gave good seepage reduction.

August 21-26: Materials S-2a, S-3a and S-3b were applied to the silty sand soils of the Lakin 2 site by spray and by ponding at different rates with single and double treatments. Results are summarized in Table 8. The site was honeycombed with old gopher holes which caused continuous difficulty in maintaining ponds and measuring seepage rates. Seepage reduction was only fair with the ponding treatments. The film thickness on the sides was thin and no penetration into the soil was observed. No cracking of the soil occurred and single applications were better than double. Spray treatments were variable with seepage reduction ranging from fair to good.

October 9-13: Materials S-1a, S-2a and S-3a were tested at the Lakin 2 site in ponding applications at two rates. Data are presented in Table 9. Seepage reduction was fair for all emulsions with S-2a appearing slightly the best. Film thickness was more uniform with S-2a than with S-1a and S-3a. Creep down the side slopes was also less with this material. Penetration was negligible for all treatments.

November 2-6: Modifications of S-1 and S-2 and unmodified S-4 were applied to the Lakin 2 site by ponding as summarized in Table 10. All modifications produced softer films than had been previously obtained with unmodified materials. Unmodified S-4 gave good seepage reduction but also produced a soft film. Film thickness was thinner on the upper slopes of the banks and no penetration into the soil was obtained. One modification caused the emulsion to break and float although water temperature in the ponds was only 70°F.

Seepage measurements on this test series were made with water stage recorders and the ponds were allowed to go dry without refilling after treatment. The seepage rates are not comparable with rates measured in other tests when the ponds were kept full.

November 24-29: Modifications of S-1 and S-2 were tested with unmodified S-3 and S-4 in multiple-treatment ponding applications at the San Marcos site. Results are presented in Table 11. Modification b lowered the effectiveness of all materials in reducing seepage. All modifications caused softer asphalt films and creep down the banks was noticeable after the ponds were drained. Material S-4 gave good seepage reduction but again produced a soft film. The asphalt penetrated all cracks and pockets of coarse sand but did not penetrate into the predominate soil. Film thickness on the banks was only fair.

SUMMARY AND CONCLUSIONS:

A soil dispersant D-1 was studied in the laboratory and in the field. Laboratory studies showed that the material completely stopped seepage through soils containing over 10 per cent clay when applied to the soil surface at rates as low as 250 pounds per acre. Field tests with infiltration cylinders confirmed this. A one acre pond was treated by spraying the soil surface with a solution of D-1b at a rate of 500 pounds of D-1b per acre. The treatment failed, apparently because the soil was cracked at the time of treatment and much of the solution ran into the cracks. This treatment is still considered promising for low-cost seepage control and additional experiments are in progress.

A seepage reducing material H-1 was studied to investigate the depth of penetration into soil and the effect of soil drying. Penetration into soil was measured by changes in hydraulic conductivity in a 4.75 inch diameter, 48 inch long, soil column. Hydraulic conductivity was determined at various depths in the column, before and after treatment with H-1 at 1000 ppm for 48 hours, by measuring head loss with piezometers installed in the column. The treatment reduced hydraulic conductivity to a depth of 4 inches, indicating that the material did penetrate at least this far.

The effect of drying on H-1 was studied in a ponding test in an operational canal near Beardsley, Arizona. Treating by applying H-1 in the ponded water, at about 1000 ppm for 48 hours, reduced the rate of water surface drop from 1.50 inches per hour to 0.60 inches per hour. Drying the canal for two months essentially destroyed the effect of treatment and the post-drying rate was 1.32 inches per hour. This test indicated that H-1 may not be suitable for treating water conveyance or storage structures which are allowed to dry during the operational cycle.

Four basic formulations and a number of modifications of experimental asphalt emulsions were subjected to exhaustive field tests. The materials were applied by spraying and by dispersion in the water held in small ponds. Field tests were supplemented by laboratory experiments. Although numerous tests were made and volumes of data were obtained, the results can be stated very simply. All modifications with solvents, emulsifiers and other additives reduced the effectiveness of the basic formulations, particularly when water temperatures exceeded 90°F. None of the materials penetrated into the soil when applied by the ponding method. Ponding application produced non-uniform coatings with thicker layers on the pond bottom and thin layers on the sloping sides. All the materials were capable of producing good seepage reduction when properly applied. Spray applications were variable in their effectiveness. These findings indicate that the ponding method of applying these materials, as presently formulated, may be suitable for reservoir linings, but not for conveyance channels. Alternate methods of application, including spray techniques, do appear promising for constructing low-cost ditch linings and are under investigation.

PERSONNEL: L. E. Myers, C. L. Jenson, G. W. Frasier.

Table 1 - Soil Analysis

SITE	Mechanical			Chemical						
	Sand	Silt	Clay	Na	Ca	Mg	$CaCO_3$	SO_4	Cl	pH
	%	%	%	meq/100g	meq/100g	meq/100g	equivalent %	meq/100g	meq/100g	
Lakin Site 1										
Ditch top	36	54	10	3.77	20.91	9.35	3.46			7.4
Ditch side	15	74	11	3.25	21.73	9.25	3.87	0.48	4.7	8.1
Ditch bottom	48	44	8	2.91	19.45	8.80	3.65			7.8
Lakin Site 2										
Canal II top	70	27	3	1.26	9.47	4.58	2.42			7.9
Canal II side	82	16	2	1.28	9.03	4.50	2.31	0.09	0.34	8.16
Canal II bottom	91	7	2	1.53	11.22	5.25	2.36			8.38
Canal III top	83	15	2	1.60	14.82	6.40	2.31			8.38
Canal III side	69	28	3	1.70	9.20	7.00	3.14	0.019	0.10	8.75
Canal III bottom	90	9	1	1.28	9.19	6.56	1.96			8.38
San Marcos										
Canal I top	59	25	16	1.28	15.90	5.10	1.63			7.69
Canal I side	49	15	36	1.59	21.50	7.00	3.46	T	0.32	7.80
Canal I bottom	57	17	26	1.32	18.95	6.05	2.75			7.80
Canal II top	57	27	16	1.54	13.93	5.07	1.18			7.55
Canal II side	62	18	20	1.31	14.75	5.00	1.35	T	0.62	7.89
Canal II bottom	52	20	28	1.56	11.95	11.80	1.88			7.82

Table 2. Soil analysis.

	Mechanical			Chemical				
SITE	Sand	Silt	Clay	Total Salts	Na	Ca + Mg	$CaCO_3$ equivalent	pH
	%	%	%	meq/1 (soil extract)	meq/100g	meq/100g	%	
Randall								
Bottom Lower	11.9	66.7	21.4	10.6	0.04	28.12	7.32	7.64
Bottom Upper	7.6	59.7	32.7	8.1	0.03	34.68	7.47	7.71
Bank Lower	14.4	61.6	24.0	7.2	0.04	30.69	7.54	7.89
Bank Upper	28.4	57.2	14.4	2.5	0.03	29.28	4.62	7.67
Beardsley								
East	52.2	34.0	13.8					
West	65.8	23.9	10.3					
Control Soil	86.7	8.9	4.4					

Table 3. Water analysis.

SITE	Total Salts	Na	Ca + Mg	HCO_3	Cl	SO_4	CO_3	pH
	meq/l	meq/l	meq/l	meq/l	meq/l	meq/l	meq/l	
Randall	1.3	0.08	0.97	0.91			0.0	7.20
Beardsley	3.2	2.09	1.18	2.15	.61	0.0	.42	7.45
Lakin		38.2	56.4		43.3	11.2		7.4
San Marcos								
Canal 4-61		7.01	9.06	3.23	9.88	2.45	T	
Canal 7-61		7.28	6.97	3.29	8.72	1.89	0	
Well 7-61		5.38	22.85	3.21	17.6	6.67	0	
Laboratory Tap	26.1	17.6	9.73	7.5		3.0	0	

Table 4. Seepage Control Treatments, San Marcos Site, June 13-17, 1961.

Pond	Material	Treatment	Treating Date	Seepage Rate			Film Thickness
				Pre-Treat	Post-Treat		
					2 hr.	48 hr.	
				in/hr	in/hr	in/hr	inch
4	none	Check		1.53	1.24	1.59	——
9	none	Check		0.96	0.84	1.09	——
2	S1a	1 gal. ponded	6/15	1.71	1.50	0.91	>1/4
6	S1a	1 gal. ponded	6/15	0.66	0.76	0.80	>1/8
10	S1a	1 gal. ponded	6/15	0.67	0.76	0.89	>1/8
3	S1b	1/2 gal. ponded	6/15	1.60	1.62	1.83	1/4
5	S1b	1/2 gal. ponded	6/15	0.85	0.81	1.02	>1/4
7	S1b	1/2 gal. ponded	6/15	0.82	0.81	0.97	>1/8
1	S1b	1 gal. ponded	6/15	0.68	0.68	1.12	3/8-5/8
8	S1b	1 gal. ponded	6/15	0.90	0.81	0.97	>1/8
11	S1b	1 gal. ponded	6/15	0.90	0.90	0.99	1/4-1/2
12	S1b	1/2 gal. spray	6/15	1.05	——	——	>1/4

Table 5. Seepage Control Treatments, San Marcos Site, July 22-30, 1961.

Pond	Material	Treatment	Treating Date	Seepage Rate			Film Thickness
				Pre-Treat	Post-Treat		
					24 hr.	48 hr.	
				in/hr	in/hr	in/hr	inch
3	none	Check		1.56	1.62	1.92	—
9	none	Check		0.78	0.90	2.10	—
6	none	Check		0.66	0.90	1.20	—
2	Slb	1/3 gal. repeated, ponded	7/25-26	1.59	1.74	1.65	>1/8
11	Slb	1/3 gal. repeated, ponded	7/25-26	0.93	0.99	1.20	>1/4
8	Slb	1/3 gal. repeated, ponded	7/25-26	0.69	1.02	0.96	>1/8
13	Slb	1/2 gal. repeated, ponded	7/25-26	1.38	0.99	1.20	—
4	Slb	1/2 gal. repeated, ponded	7/25-26	0.78	0.81	1.20	>1/4
10	Slb	1/2 gal. repeated, ponded	7/25-26	0.63	0.81	1.05	1/4-1/2
14	Slf	1/2 gal. repeated, ponded	7/25-26	1.23	0.96	1.35	—
1	Slf	1/2 gal. repeated, ponded	7/25-26	0.78	0.96	0.90	>1/8
7	Slf	1/2 gal. repeated, ponded	7/25-26	0.51	0.51	0.57	>1/8
15	Slb	1 1/2 gal. spray	7/29	2.28	2.04	2.00	0
12	Slb	1 1/2 gal. spray	7/29	1.08	—	0.72	1/4
5	Slb	1 1/2 gal. spray	7/29	0.75	—	0.62	>1/8

Table 6. Seepage Control Treatments, San Marcos Site, July 31 to August 11, 1961.

Pond	Material	Treatment	Treating Date	Seepage Rate			Film Thickness
				Pre-Treat	Post-Treat		
					24 hr.	48 hr.	
				in/hr	in/hr	in/hr	inch
20	none	Check	——	1.56	0.99	1.26	——
25	none	Check	——	0.88	0.51	0.54	——
28	none	Check	——	2.04	1.80	0.43	——
16	S2b, S2a	1/3 gal. repeated, ponded	8/1 & 8	2.40	1.02	1.59	1/16-1/4
18	S2b, S2a	1/3 gal. repeated, ponded	8/1 & 8	2.00	0.18	0.48	1/4-1/2
26	S2b, S2a	1/3 gal. repeated, ponded	8/1 & 8	1.00	0.33	0.47	1/8-1/4
19	S2b, S2a	1/2 gal. repeated, ponded	8/1 & 8	2.28	0.27	0.24	1/4-1/2
27	S2b, S2a	1/2 gal. repeated, ponded	8/1 & 8	1.32	0.36	0.46	1/4
23	S2b, S2a	1/2 gal. repeated, ponded	8/1 & 8	1.08	0.33	0.32	1/4-3/8
29	S2f, S2e	1/2 gal. repeated, ponded	8/1 & 8	2.04	1.05	1.06	——
17	S2f, S2e	1/2 gal. repeated, ponded	8/1 & 8	1.32	0.33	0.39	——
24	S2f, S2e	1/2 gal. repeated, ponded	8/1 & 8	0.96	0.21	0.18	——
30	S2b	Spray	8/3	2.16	0.93	1.26	——
32	S2b	Spray	8/3	2.08	1.80	1.70	——
22	S2b	Spray	8/3	2.00	1.89	1.41	——
21	S1b	Spray	8/3	1.80	1.71	1.71	——
31	S1b	Spray	8/3	1.68	1.32	1.58	——

Table 7. Seepage Control Treatments, Lakin 1 Site, August 9-11, 1961.

Pond	Material	Treatment	Treating Date	Seepage Rate Pre-Treat	Seepage Rate Post-Treat 24 hr.	Seepage Rate Post-Treat 48 hr.	Film Thickness
				in/hr	in/hr	in/hr	inch
1	none	Check	——	2.10	1.92	2.36	——
8	none	Check	——	3.48	3.12	3.36	——
12	none	Check	——	3.66	2.80	2.54	——
2	S2a	1/2 gal. repeated, ponded	8/10	1.80	0.76	0.56	1/16
5	S2a	1/2 gal. repeated, ponded	8/10	3.54	0.50	0.24	1/8
10	S2a	1/2 gal. repeated, ponded	8/10	3.10	0.64	0.40	1/16-3/8
3	S2a	1/2 gal., ponded	8/9	2.28	0.54	0.56	1/16
6	S2a	1/2 gal., ponded	8/10	2.76	0.32	0.34	1/8
11	S2a	1/2 gal., ponded	8/10	2.40	1.28	0.66	1/16
4	S2a	1 gal., ponded	8/9	3.72	0.12	0.28	1/16
7	S2a	1 gal., ponded	8/10	2.10	0.44	0.64	1/8
9	S2a	1 gal., ponded	8/10	2.40	0.64	0.60	1/16
13	S2a	1 gal., spray	8/11	2.10	——	1.36*	1/16-1/4
14	S2a	1 gal., spray	8/11	2.10	——	1.48*	1/16-1/4
15	S2a	1 gal., spray	8/11	3.12	——	0.28	1/16

* 48 hr. seepage rate possibly increased by gopher holes. Ponds 13 and 14.

Table 8. Seepage Control Treatments, Lakin 2 Site, August 21-24, 1961.

Pond	Material	Treatment	Treating Date	Seepage Rate Pre-Treat	Seepage Rate Post-Treat 24 hr.	Seepage Rate Post-Treat 48 hr.	Film Thickness
				in/hr	in/hr	in/hr	inch
A7	none	Check		2.52	2.74	3.26	———
A18	none	Check		6.30	———	———	———
A1	S2a	1/4 gal. repeated, ponded	8/21-22	7.5	1.08	1.14*	1/8-1/4
A3	S2a	1/4 gal. repeated, ponded	8/21-22	5.46	0.93	1.65	1/4-1/2
A6	S2a	1/4 gal. repeated, ponded	8/23-24	2.40	1.30	1.17	1/8-1/4
A2	S2a	1/2 gal., ponded	8/21	6.48	0.70	0.66	1/8-1/4
A4	S2a	1/2 gal., ponded	8/21	5.40	0.72	0.81	1/8-5/8
A5	S2a	1/2 gal., ponded	8/21	5.04	0.78	0.72	1/8-1/2
A8	S3a	1/2 gal., repeated, ponded	8/23-24	2.28	0.57	0.92*	1/8-3/4
A11	S3a	1/2 gal., repeated, ponded	8/23-24	12.18	1.00	1.25	1/16
A14	S3a	1/2 gal., repeated, ponded	8/23-24	8.04	0.59	1.53*	3/16-1/4
A9	S3a	1/2 gal., ponded	8/23	3.42	0.57	0.60*	1/16-1/4
A12	S3a	1/2 gal., ponded	8/23	6.78	0.67	0.76	1/16-1
A15	S3a	1/2 gal., ponded	8/23	7.56	0.45	0.53	1/8-3/8
A10	S3a	1 gal., ponded	8/23	3.51	0.21	0.25	1/16
A13	S3a	1 gal., ponded	8/23	8.88	0.99	0.95	1/8-1/2
A16	S3a	1 gal., ponded	8/23	7.68	0.17	0.31	1/8
A17	S3b	1/2 gal., ponded	8/23	7.80	0.55	1.23	———

Table 8. Seepage Control Treatments, Lakin 2 Site, August 21-24, 1961. (cont.)

Pond	Material	Treatment	Treating Date	Seepage Rate Pre-Treat	Seepage Rate Post-Treat 24 hr.	Seepage Rate Post-Treat 48 hr.	Film Thickness
				in/hr	in/hr	in/hr	inch
A19	S3a	1 gal., spray	8/24	4.44	1.13	1.73	——
A20	S3a	1 gal., spray	8/24	6.54	0.76	0.93	1/16-1/4
A21	S3a	1 gal., spray	8/24	4.26	0.44	0.30	1/16-1

* Gopher holes may have influenced seepage rate.

Table 9. Seepage Control Treatment, Lakin 2 Site, October 9-12, 1961.

Pond	Material	Treatment	Treating Date	Seepage Rate: Pre-Treat (in/hr)	Seepage Rate: Post-Treat 24 hr. (in/hr)	Seepage Rate: Post-Treat 48 hr. (in/hr)	Film Thickness (inch)
B1	S1a	1 gal., ponded	10/9	——	——	.42	1/32-3/8
C6	S1a	1 gal., ponded	10/10	7.65	0.98	.86	1/16-1
B11	S1a	1 gal., ponded	10/12	2.43	0.46	——	1/16-3/8
B2	S2a	1 gal., ponded	10/9	——	——	.29	1/8-1/2
C7	S2a	1 gal., ponded	10/10	6.96	0.62	.69	1/16-1/4
B12	S2a	1 gal., ponded	10/12	2.91	0.48	——	1/16-1/4
B3	S3a	1 gal., ponded	10/9	——	——	.63	1/8-5/16
C8	S3a	1 gal., ponded	10/10	6.48	0.38	.69	1/16-3/8
B13	S3a	1 gal., ponded	10/12	3.06	0.78	——	1/16-1 1/8
B6	S1a	1/2 gal., ponded	10/9	6.63	——	.72	1/16-3/8
C1	S1a	1/2 gal., ponded	10/9	3.69	——	.81	1/16-1/8
C11	S1a	1/2 gal., ponded	10/10	2.73	0.62	.69	1/16-3/8
B7	S2a	1/2 gal., ponded	10/9	8.85	——	.83	1/16-1/4
C2	S2a	1/2 gal., ponded	10/9	3.42	——	.65	1/16-1/4
C12	S2a	1/2 gal., ponded	10/10	2.73	0.33	.69	1/16-1/4
B8	S3a	1/2 gal., ponded	10/9	8.94	——	.78	1/16-5/16
C3	S3a	1/2 gal., ponded	10/9	3.84	——	.53	1/32-1/8
C13	S3a	1/2 gal., ponded	10/10	3.45	0.72	.77	1/16-3/4
B4		untreated	——	4.74	4.35	——	——
B5		untreated	——	3.99	3.96	——	——
C5		untreated	——	5.67	5.31	——	——

Table 10. Seepage Control Treatment, Lakin 2 Site, November 2-6, 1961.

Pond	Material	Treatment	Treating Date	Seepage Rate		Film Thickness
				Pre-Treat	Post 4 hr	
					in/hr	inch
B4	S4a	1 gal. ponded	11/2	4.74	0.29	1/64-1/8
C4	S4a	1/2 gal. ponded	11/2	3.07	1.95	>1/8
B5	S1c	1 gal. ponded	11/2	3.96	0.70	1/4-1/8
C18	S1c	1 gal. ponded	11/2	7.38	0.30	1/32-1/8
C5	S2c	1 gal. ponded	11/2	5.31	0.78	1/16-1/8
B14	S2c	1 gal. ponded	11/2	2.79	0.36	1/16
C9	S2b	1 gal. ponded	11/2	2.45	1.29	1/16-3/8
B15	S2d	1 gal. ponded	11/2	3.36	1.50	1/16
C10	S1b	1 gal. ponded	11/2	1.80	1.17	1/16-1/2
C19	S1d	1 gal. ponded	11/2	3.00	0.87	1/32-1/16

Post-treatment seepage rates were taken from water stage recorder graph. Seepage rates were taken From graph without refilling pond to operating depth.

Table 11. Seepage Control Treatment, San Marcos Site, November 24-29, 1961.

Pond	Material	Treatment	Treating Date	Seepage Rate Pre-Treat	Seepage Rate Post-Treat 24 hr.	Seepage Rate Post-Treat 48 hr.	Film Thickness
				in/hr	in/hr	in/hr	inch
1	S1a	1/2 gal. repeated, ponded	11/27-28	1.26	0.317	0.176	3/16-3/8
2	S1b	1/2 gal. repeated, ponded	11/27-28	0.60	0.18	0.184	3/16
3	S1c	1/2 gal. repeated, ponded	11/27-28	2.13	0.13	0.085	1/4
4	S2a	1/2 gal. repeated, ponded	11/27-28	2.13	0.117	0.117	1/8-1/4
5	S2b	1/2 gal. repeated, ponded	11/27-28	1.80	0.195	0.183	1/8
6	S2c	1/2 gal. repeated, ponded	11/27-28	1.20	0.105	0.111	1/16-1/8
7	S2c	1/2 gal. repeated, ponded	11/27-28	2.33	0.126	0.092	1/8-1/4
8	S2d	1/2 gal. repeated, ponded	11/27-28	2.00	0.166	0.150	1/8
9	S3a	1/2 gal. repeated, ponded	11/27-28	2.39	0.180	0.121	1/8-1/4
10	S4a	1/2 gal. repeated, ponded	11/27-28	2.15	0.114	0.06	1/8-3/16

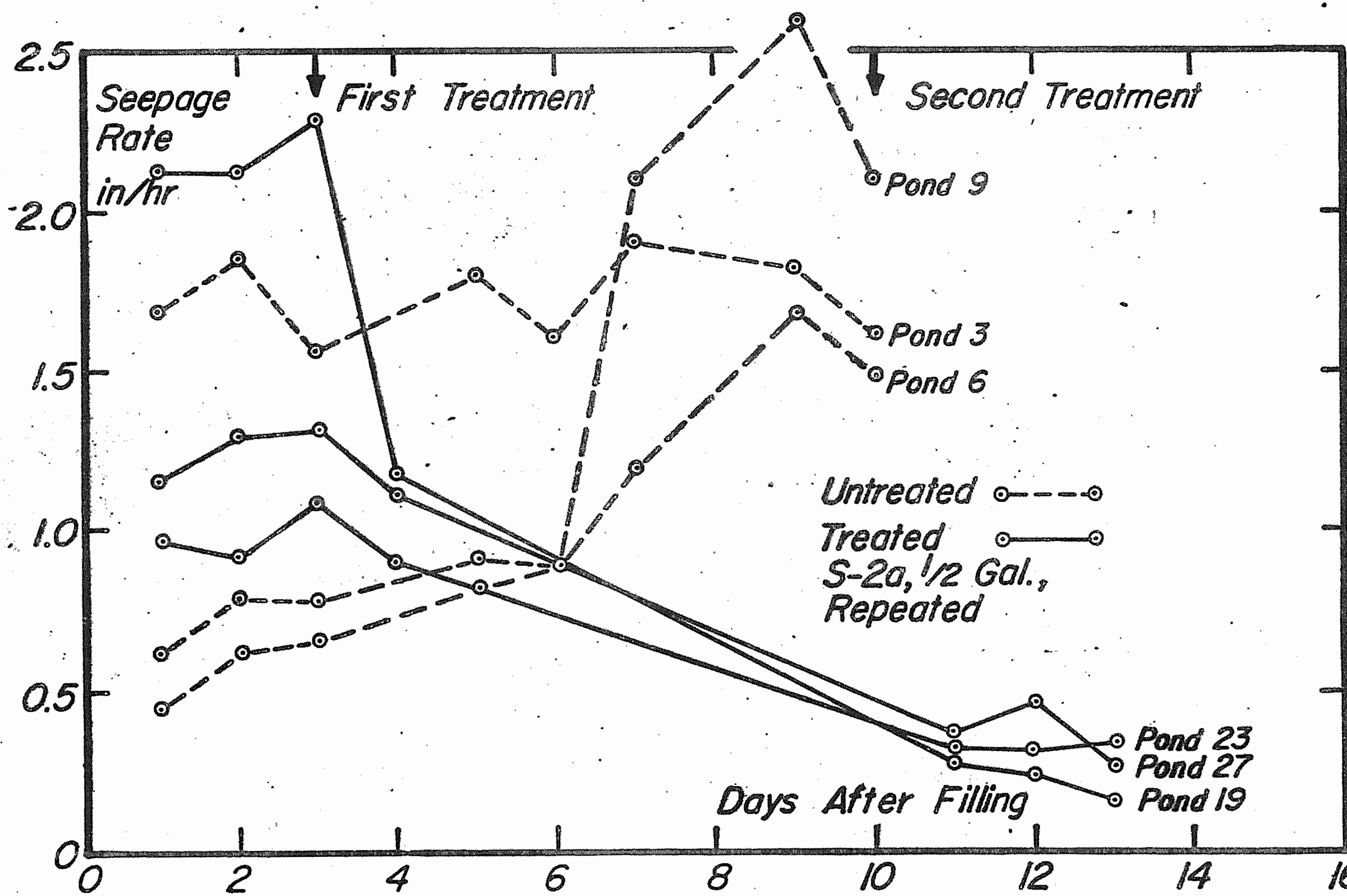
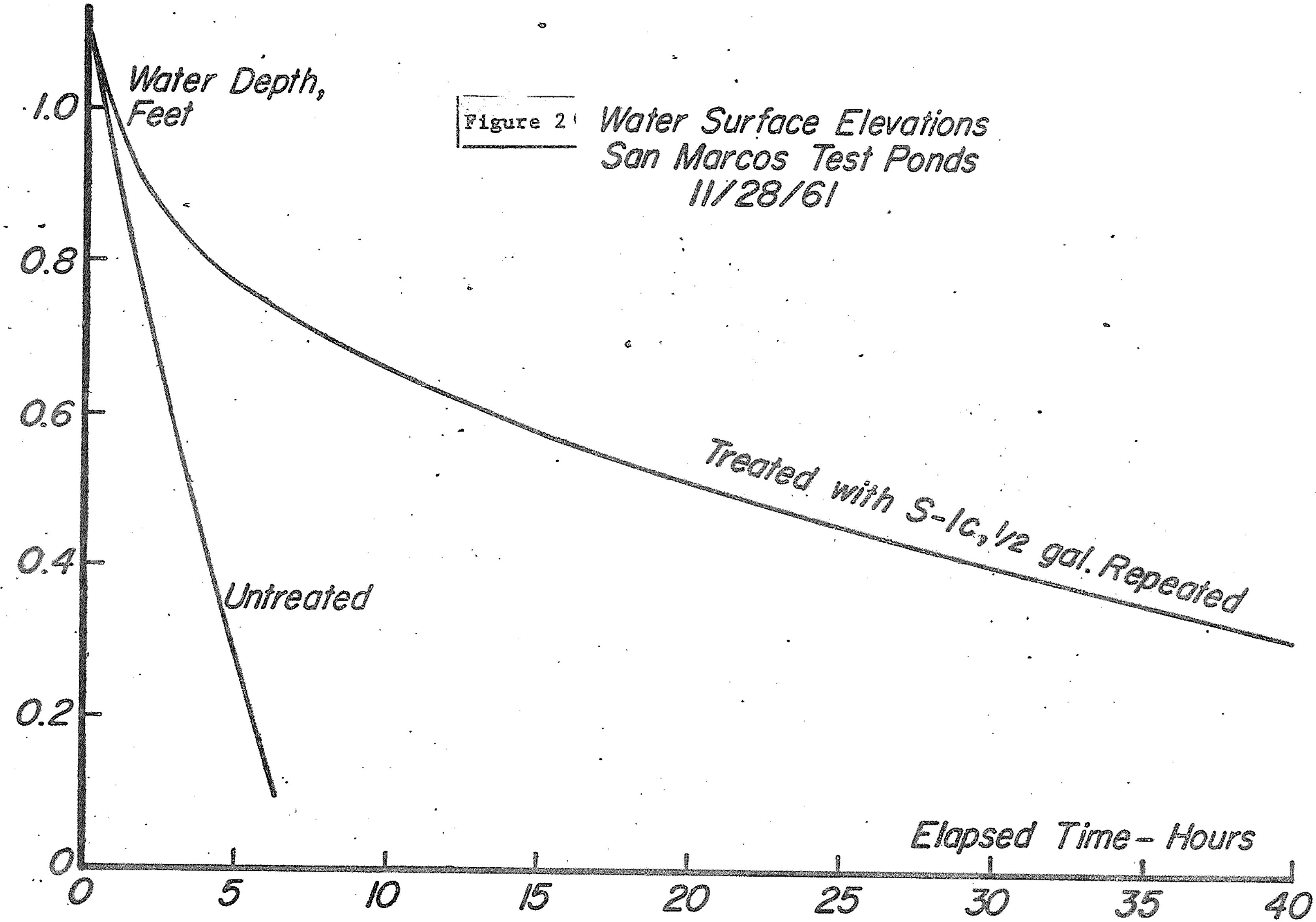


Figure 1.--Typical seepage rates, San Marcos test site.

Figure 2


Water Surface Elevations
San Marcos Test Ponds
11/28/61
Water Depth, Feet
1.0
0.8
0.6
0.4
0.2
0
Untreated
Treated with S-1c, 1/2 gal. Repeated
Elapsed Time - Hours
0
5
10
15
20
25
30
35
40

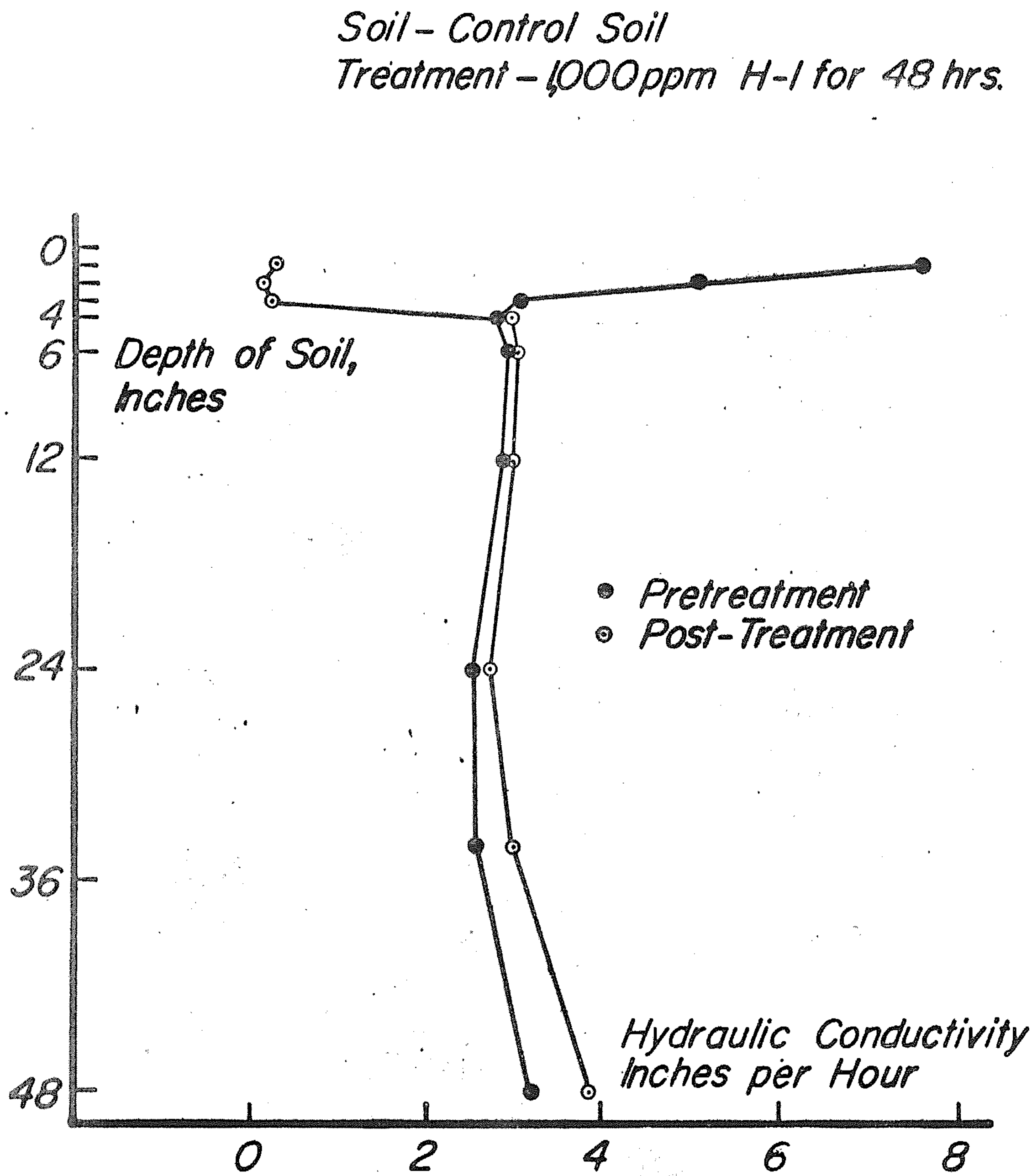


Figure 3.--Hydraulic conductivity in a soil column before and after treatment with material H-1.

TITLE: FIELD APPLICATION OF FALLING-HEAD TECHNIQUE FOR SEEPAGE METERS AND OF DOUBLE-TUBE METHOD FOR HYDRAULIC-CONDUCTIVITY MEASUREMENT

LINE PROJECT: SWC 4-gG1 CODE: Ariz.-WCL-14

I. FALLING HEAD-TECHNIQUE FOR SEEPAGE METERS

INTRODUCTION:

Development of suitable field equipment and procedures was considered necessary for routine application of the falling-head principle (17) for determining seepage in canals or reservoirs and hydraulic-conductivity of bottom materials. Verification of the theory, which was developed with an electrical resistance network, was also desirable. Restricting and sealing layers often play important roles in seepage, recharge, and other phenomena dealing with movement of water into soil below inundated areas. Procedures were therefore developed to detect the presence and to measure pertinent characteristics of layers of low hydraulic conductivity, including seals from artificial soil sealants for reducing seepage.

PROCEDURE:

A. Equipment and field procedure.

The field equipment consists essentially of three parts, the seepage cup, the falling level reservoir, and the manometer (Figure 1). The seepage cup is placed in the bottom of the canal or reservoir. The falling level reservoir is connected to the seepage cup and it is used to raise the pressure head inside the cup an inch or so above that in the surrounding canal. The subsequent rate of fall of the water surface in the reservoir, from which the seepage is calculated, is measured with an inverted vacuum U-tube manometer, which is located on the bank of the canal for convenient measurement. A hand pump is used to evacuate the desired amount of air from the manometer. A valve is placed in the tubing above the seepage cup to the falling-level reservoir. Closing this valve permits rapid measurement of the balanced-flow level. The diameter of the seepage cups used is 10 inches. Soft-rubber U-rings are used in the cylindrical part and in the lid of the seepage cup to provide the necessary sealing action. The seepage cup is of the Nevada type in that it has a completely removable lid. Upon installation, the lid is removed to eliminate surges inside the cup which might otherwise occur and could disturb the natural condition of the bottom material.

After raising the falling-head reservoir an inch or so (raising the level more than one inch may cause piping or blow-outs below the seepage cup) the subsequent rate of fall of the water level is measured with the manometer on the bank. The water level in the manometer tube connected to the seepage cup will fall, whereas that in the manometer tube connected to the free water will rise. At any time, however, the difference between the water levels in the manometer is equal to the head difference between the water inside and outside the seepage cup. This is also true when the water level in the canal is not constant during the measurements. If it is desired to measure the hydraulic conductivity K of the bottom material in addition to the seepage, the valve above the seepage cup, which is normally open, is closed after the completion of the falling-level measurements. The factor H_b is then read as the stable difference between the water levels in the manometer tubes. Enough time and water level readings should be taken on the manometer tubes during the falling level measurements to construct accurate curves of the rate of fall and rate of rise of the water level in the manometer tubes. Using suitable inserts in the falling-level reservoir, the time required for the falling-level measurements can generally be kept below ten minutes.

B. Seepage and hydraulic-conductivity calculations.

The readings of the water level in the manometer tube are plotted against time to yield a graph such as Figure 2. Seepage is computed from the rate of divergence of the curves at the point of intersection. This rate can be determined by constructing tangents to the curves at this point, and to evaluate the vertical distance $\bar{H}$ between the tangents at a distance of a unit time interval (one minute, for instance) from the point of intersection. The term $\bar{H}$ is then essentially the velocity of the falling-level in the reservoir at $H = 0$, so that only correction for the areas needs to be made to convert $\bar{H}$ into seepage. The formula for calculating the seepage rate is then

$$I_s = \frac{R_v^2}{R_c^2} \bar{H} , \qquad (1)$$

where R_v is the radius of the falling-level reservoir, and R_c is the radius of the seepage cup. This equation applies to a manometer tube that is much smaller than the diameter of the falling-level reservoir.

The calculation of K of the bottom material is based on equation (3) in (22), which can be written as

$$K = \frac{I_s R_c}{F_f H_b} \tag{2}$$

The factor F_f is dimensionless, and it was evaluated by resistance network analog. Graphs are presented (figures 2 and 5) in (22) from which F_f can be evaluated for the depth of penetration of the seepage cup (expressed as $\frac{d}{R_c}$) and for the depth D of material of much lower conductivity below the bottom of a canal or reservoir (expressed as $\frac{D}{R_c}$), or the depth D_p of material of much higher conductivity (expressed as $\frac{D_p}{R_c}$), respectively, than the bottom material in which the seepage cup is placed. If the depth to material of different conductivity exceeds the diameter of the seepage cup, F_f is essentially constant so that the medium can be considered to be uniform under those conditions. The only factor controlling F_f is then the depth of penetration of the seepage cup in relation to the cup radius.

C. Hydraulic conductivity of slowly permeable layers.

The principle of K-determination using the balanced-flow level is based on two assumptions: (1), the conductivity conditions below the seepage cup are the same at $H = 0$ as at $H = H_b$, and (2), the seepage component flow from the cup is the same at $H = 0$ as at $H = H_b$.

Both assumptions will be valid if the bottom material is uniform or underlain by material of much lower conductivity. These conditions will be evidenced by H_b-values that are small in comparison to the water depth h above the seepage cup. The assumptions will not be valid where the bottom material of the canal or reservoir in which the seepage cup is placed is of much lower permeability than the underlying material. Under those conditions, seepage gradients will be high, which will be evidenced by H_b-values that are not small in comparison with h.

At large H_b, the first assumption may lose its validity because of partial desaturation of the bottom material below the cup due to the pressure reduction inside the cup. The H_b-value determined in the field by closing the valve above the seepage cup may, therefore, be in error. The H_b-value can in this case be estimated by extrapolating the rate of fall $\frac{dH}{dt}$ of the water level in the reservoir for small values of H to $\frac{dH}{dt} = 0$. Using this corrected H_b, K is calculated with equation (2). This K-value is then used to estimate the pressure p below the bottom of the relatively impervious bottom material, according to the equation

$$p = h + D_p - D_p \frac{I_s}{K} .$$

This p-value is then used to obtain a first estimation of the seepage I_{H_b} at the balanced-flow level according to the equation

$$I_{H_b} = K \frac{h - H_b + D_p - P}{D_p} .$$

The value for I_{H_b} thus obtained is used in equation (2) to calculate a second value of K, which in turn is used to calculate a second value of p, after which a second value for I_{H_b} is calculated. This process is continued until consistent values for I_{H_b}, K, and p are obtained. This procedure does not only yield the hydraulic conductivity of the slowly permeable bottom material, but also estimates regarding the pressure conditions, which may be positive or negative, beneath the relatively impermeable layer. This procedure applies for slowly permeable layers that are not completely penetrated by the seepage cup, i. e., $d<D_p$.

If the slowly permeable layer is very thin, such as with natural or artificial seals, the seepage meter may penetrate the layer completely ($d>D_p$). The seepage meter is then used as a variable-head permeameter and information is yielded in terms of an hydraulic impedance of the slowly permeable layer. This impedance, which is the thickness of the seal divided by the conductivity of the seal, is calculated as the balanced-flow level divided by the seepage. This equation becomes evident by considering the seepage meter as a falling-head permeameter, whereby the impedance is calculated as the slope of a line in a plot of $\frac{dH}{dt}$ versus H. Since the layer from which the impedance is determined must only be present inside the seepage cup, the layer outside the cup must be removed or broken up for a distance of approximately R_c from the wall of the seepage cup (see (22), where it is shown that the effect of conditions beyond 1.7 R_c from the center of the cup or inner tube are negligible). This procedure assumes then that the entire head due to water depth above the seepage cup is dissipated across the sealing layer. If this assumption does not hold, the seal inside the cup can also be removed and the seal impedance is evaluated as the difference between the impedance before and after removing the seal inside the cup. This procedure can also be applied in evaluating artificial seals from seepage reducing materials. The impedance of the seal is then determined as the difference between the impedance before and after application of the sealant through the seepage cup. This procedure is valid if the sealing action does not take place beyond the depth of penetration of the seepage cup. More research regarding the use of seepage meters in evaluating soil sealants is in progress, however.

The impedance is a more appropriate term for describing the performance of seepage reducing materials, as evaluated with seepage cups, than the percentage reduction in seepage from the cup due to application of the material. The percentage reduction would over-estimate the seepage reduction obtained by treating the entire wetted perimeter of the canal or reservoir. This is due to the fact that the area outside the seepage cup is not treated with the sealant, so that the pressures below the seal inside the cup are not as low as the pressures below a seal of much larger extent. The percentage reduction in seepage from the cup would only correctly estimate the percentage reduction in seepage from treating the entire wetted perimeter if the reduction measured with the cup is 0% or 100%.

D. Field studies.

The equipment and procedures for the falling-head seepage meter technique with the vacuum manometer were tested at a number of locations in the Salt River Valley of Arizona and in the Fallon area of Nevada. The Nevada location was selected because of the very high seepage rates that have been reported for that area. The studies in the Salt River Valley consisted of three parts.

A seepage meter was used in connection with the evaluation of a commercial sealing material (Laboratory code H-1) by the Bureau of Reclamation and the Maricopa County Municipal Water Conservation District No. 1 at Beardsley, Arizona. The evaluation was carried out in a 400-ft ponded section of the Main Canal. The bottom width of the canal was approximately ten feet and the water depth four feet. A 14-inch diameter seepage cup was placed in the center of the bottom in the middle region of the ponded section. During the two-week "seasoning" period of the canal, which was completely dry prior to the test, the sealant was applied through the seepage cup so as to give a 1000 ppm concentration inside the cup. Several falling-head measurements were taken daily before and after application to evaluate the performance of the sealing material. A comparison was then made with the seepage reduction obtained by the Bureau of Reclamation for the entire canal.

A preliminary attempt was made to correlate seepage meter results with the acoustic properties of the bottom material as obtained with a portable seismograph. If such correlations would appear to exist, the utility of the seepage meter for evaluating canal seepage would be greatly increased and the seismograph would be a tool in logging canals for seepage. The canal section selected for this study was also in the Main Canal of Maricopa County Municipal Water Conservation District No. 1 at Beardsley, Arizona. When the canal was dry, a section of 1 3/4 mile was logged in June with an M-D 1 refraction seismograph. The stations were located in the bottom and spaced 200 ft. After the canal had been in use for about one month for supplying gravity water to the District, seepage measurements were made in July on a 4000-ft section. The cup locations were spaced

50 ft, and for each location, cups were installed in the center of the canal bottom and near both banks of the canal. A permanent meter was also installed. This meter was read daily to observe variations of the seepage with time. At the end of the irrigation season, seismic logs were again obtained for a section of about 2200 feet to determine whether the acoustic properties of the bottom material prior to the irrigation season differed from those after the season.

The third application of seepage meters was in connection with an experimental recharge pit operated by Maricopa County Municipal Water Conservation District No. 1 at Beardsley, Arizona, and the Institute for Water Utilization of the University of Arizona. The recharge rates were not considered to be sufficiently high and the question was whether removal of bottom material would increase the recharge rate. The seepage meters were used here to determine whether the low recharge was due to low conductivity of bottom material, or to restricting layers at some distance below the bottom. In the first case, removal of approximately one foot of bottom material could be expected to increase the recharge. In the second case, deeper excavations to break up restricting layers would offer greater promise for increased recharge.

E. Model studies.

Model studies were carried out in the laboratory to verify the principles of the falling-head technique for measuring seepage, hydraulic conductivity, and seepage gradients. In addition, the validity of the principle of measuring hydraulic impedances of semi-permeable layers by considering the seepage cup as falling-head permeameters, was also studied with a model study. The investigations were carried out in a 2 x 2 ft box which was filled with 9 inches of sand of approximately 0.5 mm mean particle diameter (Figure 3). The sand was drained at the bottom by a layer of gravel in which a perforated drainage tube was placed. A pair of piezometers, 6 inches apart vertically, was placed through each of the four walls of the box to measure vertical gradients in the sand. After saturating the sand, seepage conditions were created by pumping water at a constant rate from the bottom drain of the box to the water standing above the sand surface. The seepage rate was determined from the flow rate measured in the recirculatory system. From the gradients measured with the piezometers, K of the sand could then be calculated. This K is referred to as K_{box} in the expression of the results. A metal cylinder with a diameter of 9.5 inches was placed in the center of the box to serve as the seepage cup. Water was added to raise the water level inside the cylinder and from the subsequent rate of fall of the water level in the cylinder I_s and K were calculated according to the falling-head seepage meter procedure. This was done for two different seepage rates and two different depths of penetration of the cylinder. The gradients were calculated as I_s/K and comparisons were made between the gradients thus calculated and the gradients observed by the piezometers.

The validity of measuring hydraulic impedances of semi-permeable layers was tested by placing inside the cylinder a 2-inch layer of fine glass beads of known conductivity. The impedance of the glass beads, $\frac{L}{K}$, was then measured according to the falling-head technique and compared with the calculated impedance from the observed K of the beads and the thickness of the layer of beads inside the seepage ring.

RESULTS AND DISCUSSION:

A. Field studies.

Seepage measurements in Nevada. Results of the field measurements obtained in Nevada are shown in Figure 4. High seepage rates were found where the bottom was free from deposits of fine or organic material. Maximum rates as high as 78 ft per day were observed. The combination of a 10-inch seepage cup, the 4-inch falling-head reservoir, and the 1/4-inch diameter manometer tubes was sufficient for measurements of these very high rates. Hydraulic conductivity was calculated for a number of seepage cup locations. In general, the bottom materials in the canal locations selected for the studies were quite sandy. The values of H_b and K for the seepage data in Figure 4 are shown below (from left to right for each canal in Figure 4).

Canal	Seepage ft/day	H_b inches	K ft/day	Seepage Gradient
Carter Ditch	0	0	3	0
	10	5.5	6	1.7
	14	3.5	16	0.9
	0	0	4	0
	9	1.6	21	0.4
	18	2.6	25	0.7
U-line	56	9.1	24	2.3
	10	4.5	7	1.4

Canal	Seepage ft/day	H_b inches	K ft/day	Seepage Gradient
U-line	8			
	13	5.2	9	1.4
	40	12	11	3.6
	78	12	21	3.7
	6	2.2	9	0.7
	56	6.9	30	1.9
	12	3.4	14	0.8
N-line	10	2.7	13	0.8
	33	3.5	34	1.0
	39	3.6	34	1.1
	10			
	12	1.0	37	0.32
	31	2.4	39	0.8
	25	1.2	70	0.4
	9			
	38	9.5	12	3.2
	15	4.3	10	1.5
	15	2.2	23	0.7
	26	7.0	14	1.9
	27	0.5	88	0.3
	9	4.5	7	1.3
	7	3.9	7	1.0

Canal	Seepage ft/day	H_b inches	K ft/day	Seepage Gradient
N-line	26	7.8	12	2.2
	52	9.1	21	2.5
	52	9.8	20	2.6
	18			
	8	3.8	6	1.3
	51	14.2	11	4.6
	8	4.2	7	1.1
	32	4.3	27	1.2
	2	2.3	4	0.5
	12			
	7	8.7	3	2.3

Evaluation of soil sealant H-1. The results of the H-1 evaluation with a seepage cup in a ponded section of the Main Canal at Beardsley, Arizona are shown in Table 1. The seepage meter results are consistent, and the seepage rate before applying the material through the cup compares with the free water surface drop. The seepage, both for seepage meter and ponding test, increased with time during the "seasoning" period.

After application of the sealant through the seepage cup, the distance H_b of the balanced-flow level below the free water surface decreased. The decrease in seepage gradients indicated by this reduction in H_b must be caused by the formation of a restricting layer below the distance of penetration of the seepage cup. If a surface seal had been formed, H_b would have been increased. The formation of a sealing layer below the depth of penetration of the seepage cup, which was one inch, may have been due to the fact that the seepage cup was placed in rather coarse sediment and did not completely penetrate this sediment. The sealing material could then have passed through the coarse sedimentary sand to form a sealing layer in the underlying finer original material.

The reduction in seepage from the cup due to application of the sealant was approximately 83%. The seepage reduction for the entire canal section was 61%. This confirms the statements made in section C under PROCEDURE, that the seepage reduction from the seepage meter tests would overestimate the seepage reduction due to treatment of the entire canal.

After the test period, the canal was allowed to dry from February 7 to April 17, when it was filled for a second post-treatment test. The results of this test, i. e., 2.5 in/hr for the seepage cup and 1.38 in/hr for the ponding test, showed that the sealing material had lost its effectiveness.

Recharge. The results of the seepage meter tests in the experimental recharge pit at Beardsley, Arizona showed that the average recharge gradient was 0.13, which indicated that the layers restricting the seepage were at some depth below the bottom of the pit. Therefore, it was recommended that a deep trench would be more effective to increase the recharge than removal of a foot or so of bottom material. The results for the individual seepage meter tests are listed below.

Results of Seepage Meter Tests, Maricopa County Municipal Water Conservation District No. 1

August 15, 1961

	Seepage in/hr		Hydraulic conductivity in/hr		Seepage gradient
	0.45		1.73		0.26
	0.32		3.85		0.08
	0.00		4.20		0.00
	0.64		6.65		0.09
	1.25		9.60		0.13
	0.32		3.16		0.10
	1.62		7.20		0.24
Average	0.67	Average	5.2	Average	0.13

The average seepage rate of 0.67 in/hr agreed very well with the rate of fall of 0.66 in/hr of the water surface in the seepage pit at the time of the measurements.

Seismic logging. The soil profile determined by the refraction seismograph is shown in Figure 5. This profile is for the first 4000 ft of the traverse. The different soil types in the profile are determined by the velocity of the seismic wave. The velocity ranges for the different soil types are shown below.

Type I - 620-1200 ft/sec

Type II - 1400-1900 ft/sec

Type III - 2000-2500 ft/sec

Type IV - >2750 ft/sec

The second traverse that was run after the canal had been dry for one month was very nearly the same as that of the first traverse. A plot of seepage rates against canal location is also shown in Figure 5. Seepage in the center of the canal was higher than at either side. A layer of soft mud is a probable reason for the lower seepage rates at the sides. The seepage rates at the permanent station decreased from 4.8 in/hr to 1.0 in/hr over a period of eight days. This was probably caused by the fact that the velocity inside the meter was zero, so that a layer of fine material could be deposited on the soil causing the decrease in seepage. This was evidenced by an increase in H_b as the seepage declined.

The data were analyzed by obtaining a mean of the seepage rates at a given seismic velocity and then plotting the mean against the seismic velocity as shown in Figure 6. The seismic velocity used is that of the second layer. The standard deviation of the mean is shown as a vertical bar in the figure. The ends of the standard deviation bars are connected to give a band on the graph.

The seepage varies considerably at a given velocity as indicated by the relatively large standard deviations in Figure 2. Although the standard deviations are large, there appears to be a trend for higher seepage rates between the velocities of 2300 and 2500 ft/sec. The higher rates are the result of a few measurements taken within a short distance; therefore, the investigation appears to be relatively inconclusive. However, it seems desirable that the studies of this nature be continued with more seepage measurements per seismic soil class. Also an attempt should be made to obtain more information regarding the soils by relating the seismic velocity of the individual soil layers to observations from test holes.

B. Model studies.

The results of the model study to determine seepage and hydraulic conductivity of sand in a square box are shown in

Table 2. Excellent agreement was obtained between measured values of seepage, hydraulic conductivity, and gradients and calculated values. The hydraulic conductivity decreased with increasing depth of penetration of the seepage cup. This is probably due to compaction of the sand below the cylinder as the cylinder was pushed into the sand. The increased compaction was also evidenced by local depression of the sand surface around the periphery of the cylinder.

The principle for measuring hydraulic impedance of slowly permeable layers was verified as follows: The permeability of fine glass beads was determined in cylinder permeameters. The results were .34, .32, .29, and .29 cm/min, or an average of 0.31 cm/min. A layer of 4.6 cm of these beads was then placed inside the cylinder in the sand box. The impedance of this layer was calculated as 4.6 ÷ .31 = 14.8 min. Before placing the layer of glass beads, the equivalent impedance of the sand was measured from the $\frac{dH}{dt}$ versus H plot as 2.5 minutes. The combined impedance of the sand and the layer of fine beads was then measured as 16.2 minutes. The difference of 13.7 minutes, which is the impedance of the layer of glass beads, agrees well with the impedance of 14.8 minutes calculated from the previously determined hydraulic conductivity of the beads and the measured thickness of the layer of beads in the cylinder.

C. Remarks.

The graphical seepage determination according to figure 2 and equation (1) is essentially the same as the can-and-hook gage technique used in connection with the seepage meter procedure developed by the Soil Conservation Service. It can be shown that this graphical procedure upon analytical development yields the equation (9) in the theoretical development of the falling-head technique (17). The graphical procedure, however, relieves the seepage calculation as with equation (9) in (17) from the assumption that I_s is not affected by H for the H-range in question. The main advantages of the graphical procedure according to figure 2 and equation (1) are the convenience of taking the measurements on the canal bank, the absence of interference of water level fluctuations during the measurements, and the statistically more reliable results obtained by determining the seepage from best fitting curves through the measured points.

In calculating the hydraulic conductivity of slowly permeable bottom materials which are not completely penetrated by the seepage cup, it may be difficult to estimate D_p in the field, because conductivity changes may occur without visual changes in the profile of the bottom materials. It may, however, be possible to use assumed values for p, for instance, p = 0 or slightly negative. The equations used for successive approximation of corrected values for D_p and p are then used to approximate D_p and K of the slowly permeable layer. Thus, if assumed values for p can be used, the procedure yields information regarding K and thickness of the slowly permeable bottom material.

If a correction Δh is to be applied to the free water surface in case of non-negligible effects of velocity-induced pressure differences on the seepage measurements, the seepage is not calculated from the rate of divergence of the curves such as in Figure 2 at their point of intersection, but at a point to the right of the intersection where the curves are a vertical distance Δh apart.

A paper entitled "Use of seepage meters in seepage and recharge investigations" is completed in which the application of the falling-head seepage meter technique in seepage and recharge investigations is discussed in greater detail.

SUMMARY AND CONCLUSIONS:

The application of a falling-head seepage meter technique in seepage and recharge investigations is discussed. The falling-head measurements are taken on the canal bank by means of an inverted U-tube and a hand vacuum pump. Curves are plotted for the falling-water level in the manometer tube connected to the seepage meter, and for the rising water level in the tube connected to the free water outside the seepage meter. The seepage is then calculated from the angle between the two curves at their point of intersection. This procedure is simple and convenient, and also independent of water level fluctuations in the canal or reservoir during the period of measurements. Hydraulic conductivity of bottom material is calculated from the balanced-flow level, the previously determined seepage rate, and dimensionless parameters which were developed by resistance network analogs. The hydraulic conductivity can be evaluated for uniform bottom material or for the top layer in case this layer is underlain by material of either much higher or much lower conductivity. The thickness of this top layer must then be known. If the top layer is relatively impermeable compared to the underlying material, the conductivity of the top layer is calculated by a process of successive approximation which also yields information regarding the pressure below the layer. If assumed values for this pressure can be used, for instance atmospheric or slightly negative, it is possible to estimate both the hydraulic conductivity and the thickness of the slowly permeable layer. This procedure is applicable to layers that extend beyond the depth of penetration of the seepage cup. For thin, restricting layers such as natural or artificial "seals," which are completely penetrated by the seepage cup, the conductivity information can be obtained in terms of the hydraulic impedance.

Potential areas of application of the falling-head technique are:

1. Canal or reservoir seepage investigations (locating leaky sections, detecting presence of restricting layers, effect of disturbance of restricting layers on seepage, checking reliability of techniques for logging seepage, etc.).

2. Recharge investigations (detecting presence and depth of restricting layers and determining measures to increase recharge).

3. Evaluation of the performance of certain artificial soil sealants for reducing seepage.

The validity of the falling-head principle for measuring seepage, hydraulic conductivity, and hydraulic impedance was demonstrated by a laboratory study where good agreement between observed and known values of seepage, hydraulic conductivity, and impedance was obtained.

PERSONNEL: H. Bouwer, R. C. Rice

II. APPLICATION OF THE DOUBLE-TUBE METHOD

INTRODUCTION:

The principles of the double-tube method for measuring hydraulic conductivity in situ above a water table (22) are basically sound and free from stringent assumptions. Major sources of uncertainty are only the possibility of entrapped air in the artificially saturated region below the auger hole, the possibility of non-uniformity of the soil within the region sampled for hydraulic conductivity, and reactions between the water and the colloidal fraction of the soil. The mechanics of the method, however, is essentially free from sources of error. Because of the role that such a method could play in soil and water management research, field procedures suitable for routine application of the method were developed. This involved the construction and testing of suitable equipment, as well as comparisons between double-tube results with results obtained by other methods. Studies were carried out in the field as well as in the laboratory. The results are discussed in detail in a paper that is in press (41). The discussion in this report will, therefore, be limited to the more important findings.

PROCEDURE:

Laboratory studies were carried out in the same sand box as previously discussed for the seepage meter studies. The purpose of these studies was to permit comparison of the double-tube results against a "standard" conductivity, which was the conductivity of the sand as a whole determined from recirculation rates and piezometer readings. Thus, the box served as a large permeameter for this purpose. After the hydraulic conductivity of the sand in the box was determined, the inner tube was pushed a certain distance in the sand. The walls of the box served as the outer tube. Since the sand in the box was underlain by a layer of gravel for adequate drainage of the sand, flow factors were selected from the graph applying to soil underlain by material of much higher conductivity (22).

Photographs and detailed description of the equipment used in the field tests are shown in (22) and (41). Factors studied in the field were the proper time spacing of the equal-level and constant-level measurements (22) to obtain consistent and reproducible results. Furthermore, a procedure for determining in the field the time that consistent results were obtained without calculating K after each measurement was developed. A record was kept of the total volume of water required for the tests as well as of the number of hours required for sufficient saturation and corresponding consistency in results.

After completion of the field tests, which were made in coarse sand, fine sand, and loam, soil samples were taken at the bottom of the auger hole for laboratory determination of hydraulic conductivity. For the two sands, which were fairly uniform, the samples were disturbed. For the loam, undisturbed samples were taken in vertical as well as horizontal directions. For this purpose the auger hole had to be excavated to considerably larger dimensions after the double-tube tests. The absence of standard methods for determining hydraulic conductivity in the field precludes comparisons between results from the double-tube method and "true" K-values. Thus, the K-values obtained from the soil samples in this study could only serve to compare general magnitudes.

The double-tube tests in the loam soil, which was an Adelanto loam with a well developed structure, showed that an undisturbed, clean soil surface at the bottom of the auger hole was required to obtain reliable results. A special hole cleaner was developed for this purpose. The working part of the hole cleaner consists of a number of parallel thin steel blades spaced about 1 cm apart. The blades are pushed in the soil and upon vertical removal of the hole cleaner, the soil tends to stick between the blades, thus yielding a clean breaking surface at the bottom of the auger hole. Dry, coarse sand is then poured on the bottom of the hole to form a 1-2 cm protective layer for the exposed macropores of the undisturbed soil.

RESULTS AND DISCUSSION:

The results of the laboratory study (Table 3) show that the most shallow penetration gives the best agreement between $K_{double-tube}$ and K_{box}. For d = 2 cm, the average $K_{double-tube}$ is only 5.6% less than K_{box}. As d increases, $K_{double-tube}$ decreases, which is probably caused by compaction of the sand near and under the cylinder as the cylinder is pushed into the sand.

Theoretically, there should be no effect of H_b on $K_{double-tube}$. The different K-values obtained for identical runs with $H_b = 0$ at d = 6 cm (Table 3) indicates that a difference in K for different H_b-values, such as for $K_{double-tube}$ at d = 2, may be due to errors in the individual tests. The sand-box study shows the validity of the principles of the double-tube method. The study also served as a check on the F_f-values, which were determined with a resistance network analog.

The results of the field studies, which were carried out with a 5-inch inner tube and an 8-inch outer tube in an auger hole of approximately 3 ft deep, are shown in Table 4. For the two sandy soils, which were in the Salt River bed, the comparison was made with K-values from disturbed samples. Since the soils are of alluvial origin, some orientation and separation of particles can be expected in the natural conditions. Thus, full agreement between the two methods was not likely to exist and the main objective of this study was to compare general magnitudes rather than exact values. In addition to laboratory permeameter tests of disturbed mixed samples prepared from moist sand, K-data were measured on water-deposited samples obtained by pouring dry sand in water-filled permeameters and replacing the remaining liquid above the sample, which contained fines in suspension, by clear water. The K-values of the mixed and of the water-deposited samples provided a range of magnitudes within which the undisturbed K could fall. The results in Table 4 show that comparable magnitudes were obtained and that K determined with the double-tube fell between the extreme K-values of the disturbed samples.

The K-value obtained in Adelanto loam in back of the Laboratory was compared with K-data from undisturbed core samples 6 cm long and 5.5 cm in diameter. Samples were taken in horizontal and vertical directions after the auger hole in which the double-tube tests were carried out was enlarged to permit the taking of undisturbed samples. Although the core samples yielded a considerable spread in K-values (from 0.0018 to 0.17 cm/min with most values between 0.015 and 0.030

cm/min), the average K agreed well with K from the double-tube method.

In working with the double-tube method in the field, it was found that if the equal-level and constant-level measurements were carried out too soon after each other, reproducible results were not always obtained. Most likely, this was due to insufficient time for the flow system below the hole bottom to return to normal conditions between measurements. Thus, an equal-level measurement was apparently influenced by the disturbance caused by the previous constant-level measurement. It was found, that allowing approximately 10 times as much time between the equal-level and constant-level measurements as it took to obtain the individual equal-level or constant-level measurements, yielded accurate and reproducible results.

To determine the point of sufficient artificial saturation below the bottom of the auger hole, which is evidenced by consistency in K-values as determined from successive combinations of equal-level and constant-level curves, a certain distance (20 cm., for instance) is selected on the inner tube standpipe and the time required for the water level in this standpipe to drop this distance is recorded for each equal-level or constant-level measurement. This time is then plotted against clock time and the points are connected so as to yield one curve for the equal-level measurements and another curve for the constant-level measurements. When the vertical distance between the curves becomes constant, consistent K-values are yielded and the field tests can be stopped. The time to reach sufficient artificial saturation for the soils in Table 4 was two to three hours for the sandy soil and 5 hours for the loam soil. The total volume of water required for each test was about 100 gal. For further detail regarding field procedures and processing of field measurements, reference is made to (41).

SUMMARY AND CONCLUSIONS:

Theory and principles of the double-tube method for measuring hydraulic conductivity of soil in situ above a water table (22) were tested in the laboratory. The studies, which were carried out in a sandbox, showed excellent agreement between the results obtained with the double-tube principle and the known hydraulic conductivity of the sand in the box, i. e., 3.87 and 4.10 cm/min, respectively.

Equipment and procedures were developed for routine application of the double-tube method in the field. Reproducible results were obtained if ten times as much time was allowed between equal-level and constant-level measurements as the time required for the individual equal-level or constant-level measurements. A procedure was also developed to determine in the field when sufficient saturation is reached, as evidenced by consistent K-values yielded by successive measurements, without having to calculate K after each set of measurements.

Of paramount importance in obtaining accurate results is an undisturbed, clean surface of the soil at the bottom of the auger hole. A special hole cleaner, consisting of a number of parallel thin steel blades, was developed for this purpose. The requirement of undisturbed soil surfaces applies to any method whereby permeability is evaluated from the rate of outflow of water from a soil cavity or well. If, for a certain method, limited accessibility precludes obtaining undisturbed surfaces for the outflow facility, the utility of such a method is seriously reduced.

The double-tube method was applied at three locations in the Salt River Valley, on a coarse sand, fine sand, and Adelanto loam. The results of the double-tube method agreed well with results obtained from disturbed samples taken at the bottom of the auger hole for the two sandy soils, and from undisturbed samples taken from the Adelanto loam. The time required for sufficient saturation and consistent results varied from two to three hours for the sandy soils and five hours for the loam soil. Approximately 100 gal. of water was required for each test. The double-tube method can best be carried out by a crew of two men. Such a crew could handle several double-tube tests simultaneously.

The double-tube method combines simplicity of equipment and operation with freedom from stringent assumptions and simplifications. The method is basically sound and the flow system from which K is determined is well defined. Air entrapment, non-uniformity or anisotropy within the soil region sampled for K, and reaction between the water and the clay fraction of the soil, are the major sources of uncertainty. Good results were obtained in laboratory and field tests of the double-tube method. The method, therefore, appears to be a suitable tool for field measurement of hydraulic conductivity of soil that is not saturated prior to the time of the measurements.

PERSONNEL: H. Bouwer, R. C. Rice

Table 1. Results of evaluation of soil sealant H-1 in Main Canal, Beardsley, Arizona, January 19 - February 6, 1961.

Date and Time		Seepage Meter Test U. S. Water Conservation Lab.		Ponding Test U. S. Bureau of Reclamation
		Seepage in/hr	H_b in	Water level drop in/hr
1/19		Seepage meter installed and section filled up		
1/20	11.00	0.80	2.5	
	11.10	0.86	2.9	
	11.45	0.80	2.5	
	12.30	0.80	2.0	0.91
	13.25	0.80	2.0	
	14.20	0.72	1.6	
	15.00	0.80	1.6	
1/23	10.50	1.50	3.0	
	11.45	1.50	2.4	
	12.50	1.60	3.2	1.07
	13.40	1.60	3.2	
	14.35	1.35	2.1	
1/24	9.05	1.75	2.1	
	10.00	1.75	2.1	
	11.00	1.75	2.1	
	11.10	Soil sealant H-1 applied through seepage cup		1.28
	12.35	1.75	1.1	
	13.25	1.65	1.1	
	14.05	1.45	1.6	
	14.35	1.40	1.1	
1/25	11.45	0.37	0.20	
	12.45	0.25	0.12	
	13.45	0.25	0.18	1.30
	14.45	0.19	0.12	
1/26	14.31	0.37	0.20	
	14.45	0.33	0.21	1.36
	14.55	0.27	0.38	
1/27	11.58	0.33	0.22	
	13.00	0.25	0.13	1.46
	13.55	0.25	0.13	
1/28				1.56
1/29				1.56

Date and Time		Seepage Meter Test U. S. Water Conservation Lab.		Ponding Test U. S. Bureau of Reclamation
		Seepage in/hr	H_b in	Water level drop in/hr
1/30	13.45	0.38	0.17	
	14.25	0.32	0.14	
1/31				1.54
2/1				pretreatment 1.55
2/3				H-1 treatment of section
2/6				Post treatment 0.60

Table 2. Results of seepage-meter tests in sand box.

		Observed values		Calculated values		
d	H_b	Seepage from box outflow	Gradient from Piezometers	I_s eq.(1)	K eq.(2)	Gradient I_s/K
cm	cm	cm/min		cm/min	cm/min	
2	0.68	0.38	0.099	0.40	3.8	0.10
2	1.45	0.80	0.20	0.84	3.8	0.21
6	1.22	0.41	0.10	0.41	3.6	0.11
6	2.46	0.81	0.21	0.80	3.5	0.23

$K_{box} = 4.1$ cm/min

Table 3. Results of sand-model studies of double-tube method. The data are listed in order of tests performed.

		Individual Test cm/min.	Average cm/min.
K_{box}		4.09	4.10
		4.12	
$K_{double\text{-}tube}$, d = 2 cm,	H_b = 0	4.06	3.87
	H_b = 0.68 cm	3.78	
	H_b = 1.45 cm	3.78	
$K_{double\text{-}tube}$, d = 6 cm,	H_b = 0	3.52	3.60
	H_b = 1.21 cm	3.60	
	H_b = 2.44 cm	3.52	
	H_b = 0	3.74	
$K_{double\text{-}tube}$, d = 10.8 cm,	H_b = 0	3.66	3.66
K_{box}		4.14	4.14

Table 4. Comparison between K from double-tube method and K from soil samples.

	$K_{double-tube}$ cm/min.	$K_{soil\ samples}$ cm/min.
Coarse sand,		1.00 1/
mean particle size approximately 0.5 mm	0.64	0.91 1/
no clay		0.53 2/
Loamy sand,		0.049 1/
65% fine sand, 31% silt, 4% clay	0.037	0.057 1/
		0.028 2/
Adelanto loam	0.036	0.032 3/

1/ Duplicate test of mixed sample.

2/ Permeameter test of water-deposited sample.

3/ Average of 6 horizontal and 5 vertical undisturbed core samples.

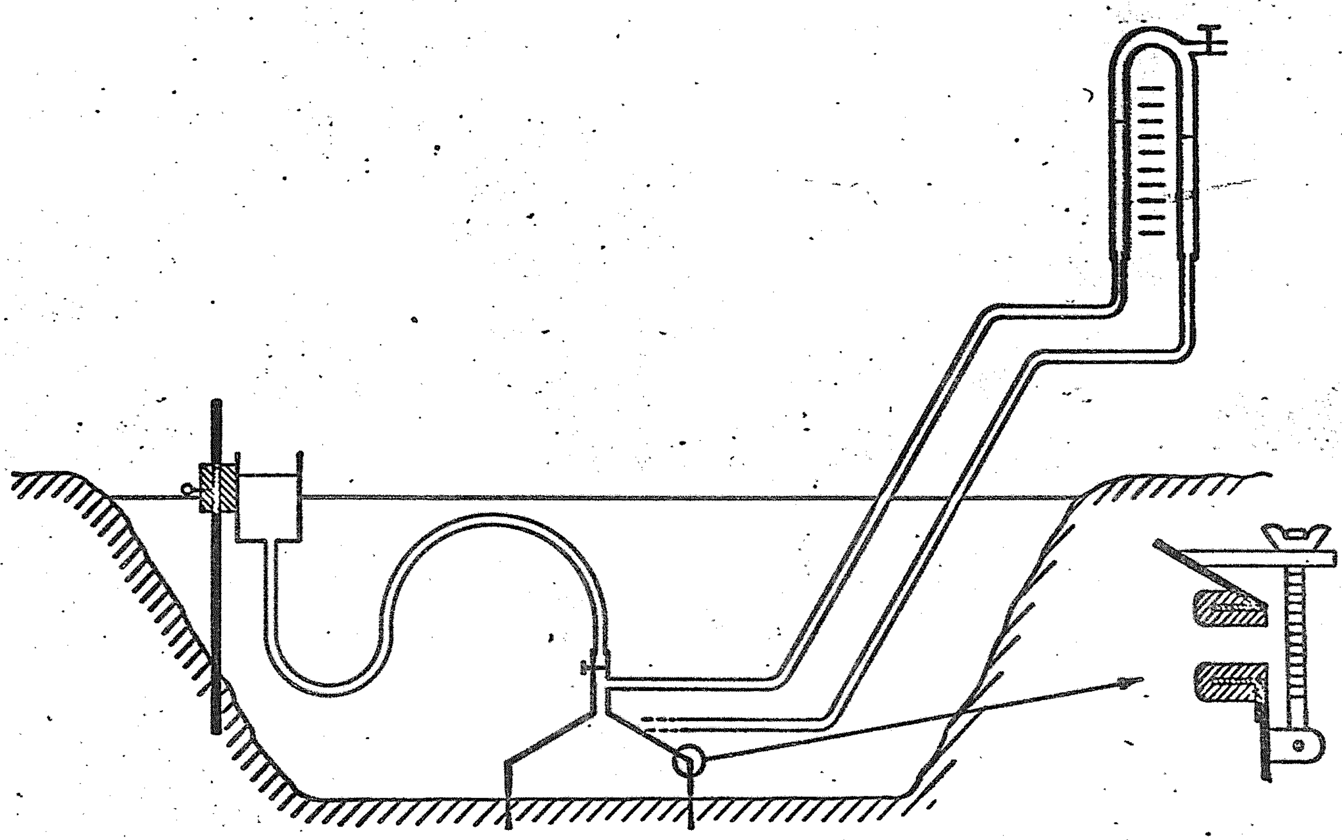


Figure 1. Sketch of seepage meter equipment in canal.

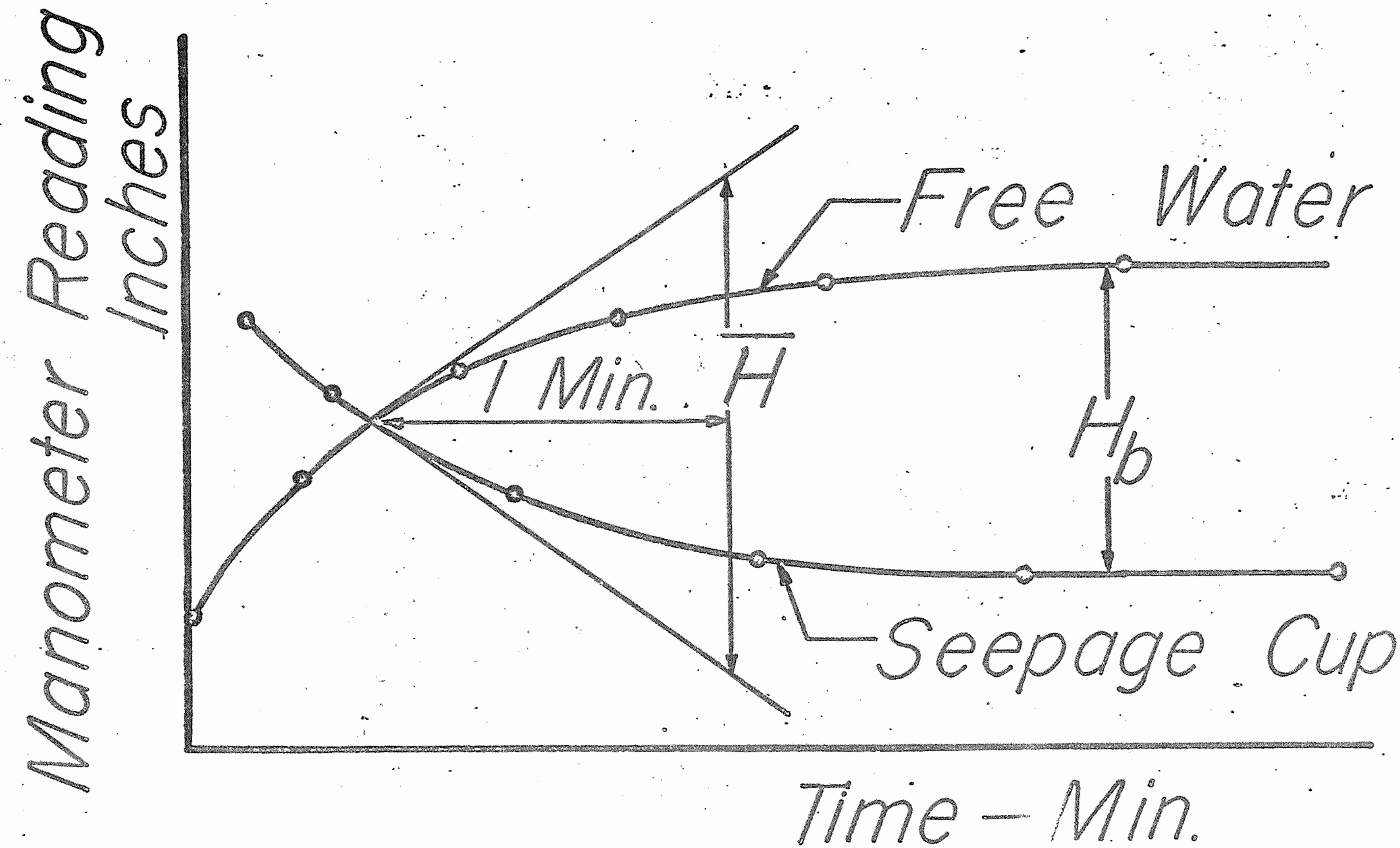


Figure 2. Curves of water level in manometer tubes versus time and evaluation of $\overline{H}$.

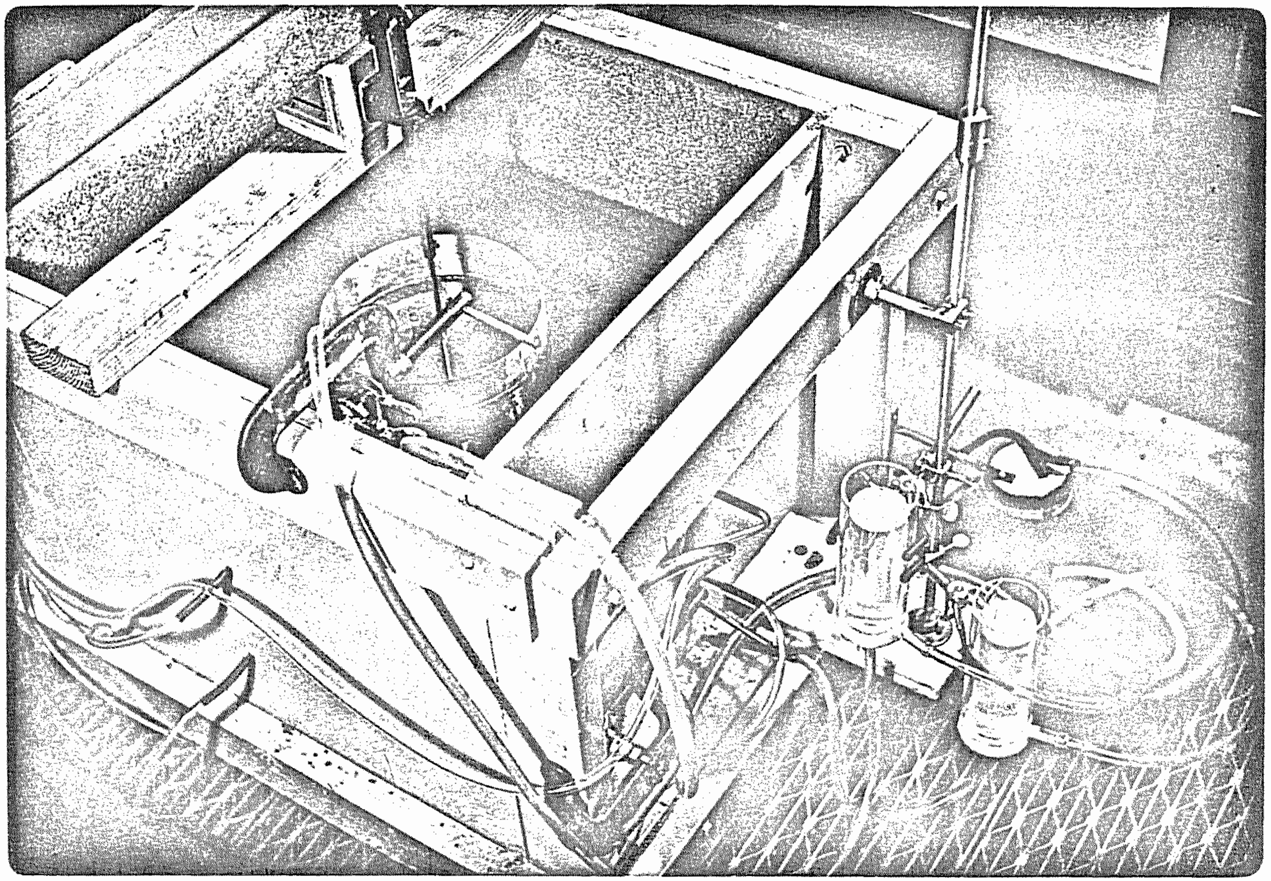
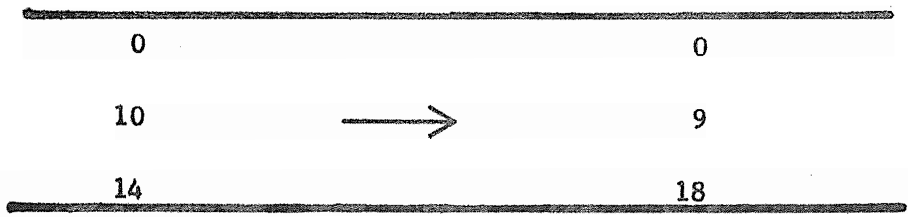
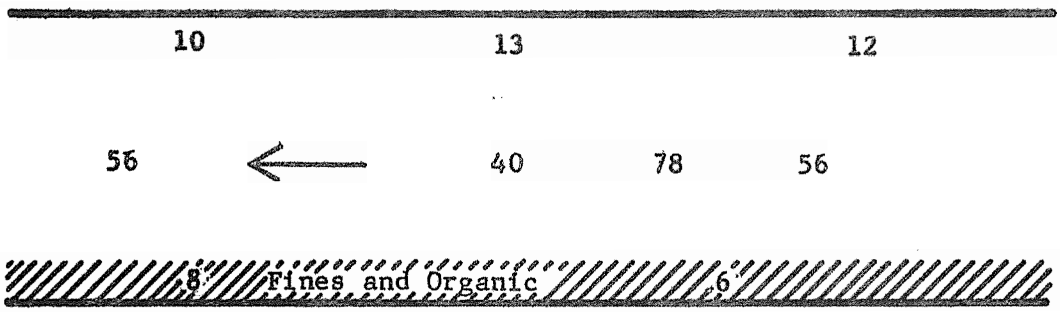


Figure 3. Sand box for laboratory tests of falling-head seepage meter technique and double-tube principle.



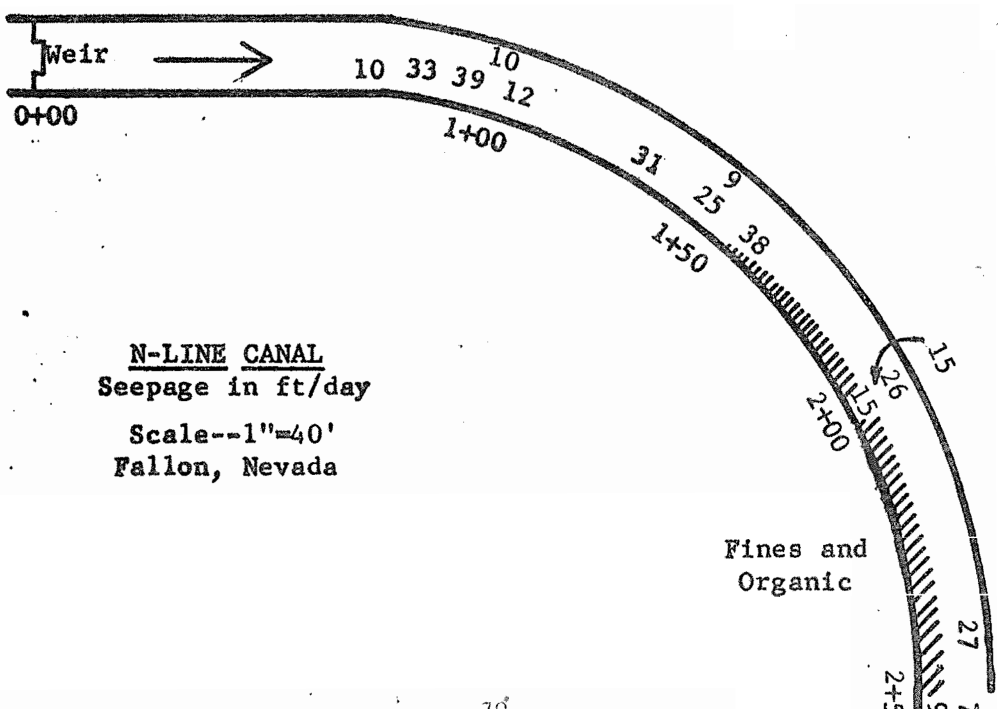
CARTER DITCH
Seepage in ft/day

Scale--1"=10'
Fallon, Nevada



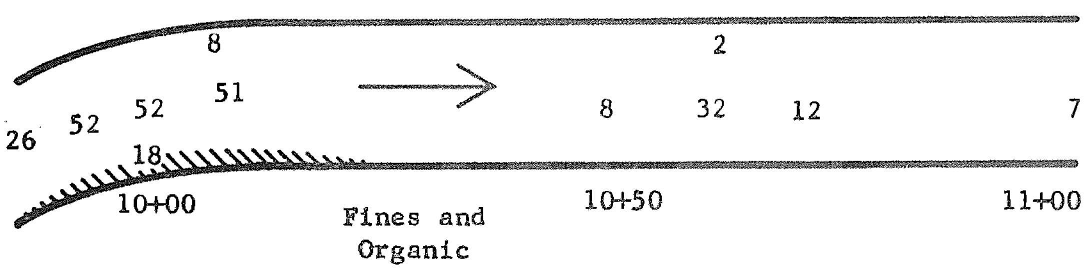
U-LINE CANAL
Seepage in ft/day

Scale--1"=10'
Fallon, Nevada



N-LINE CANAL
Seepage in ft/day

Scale--1"=40'
Fallon, Nevada



N-LINE CANAL

Seepage in ft/day

Scale--1"=20'

Fallon, Nevada

Figure 4. Results of seepage meter tests in Fallon area, Nevada.

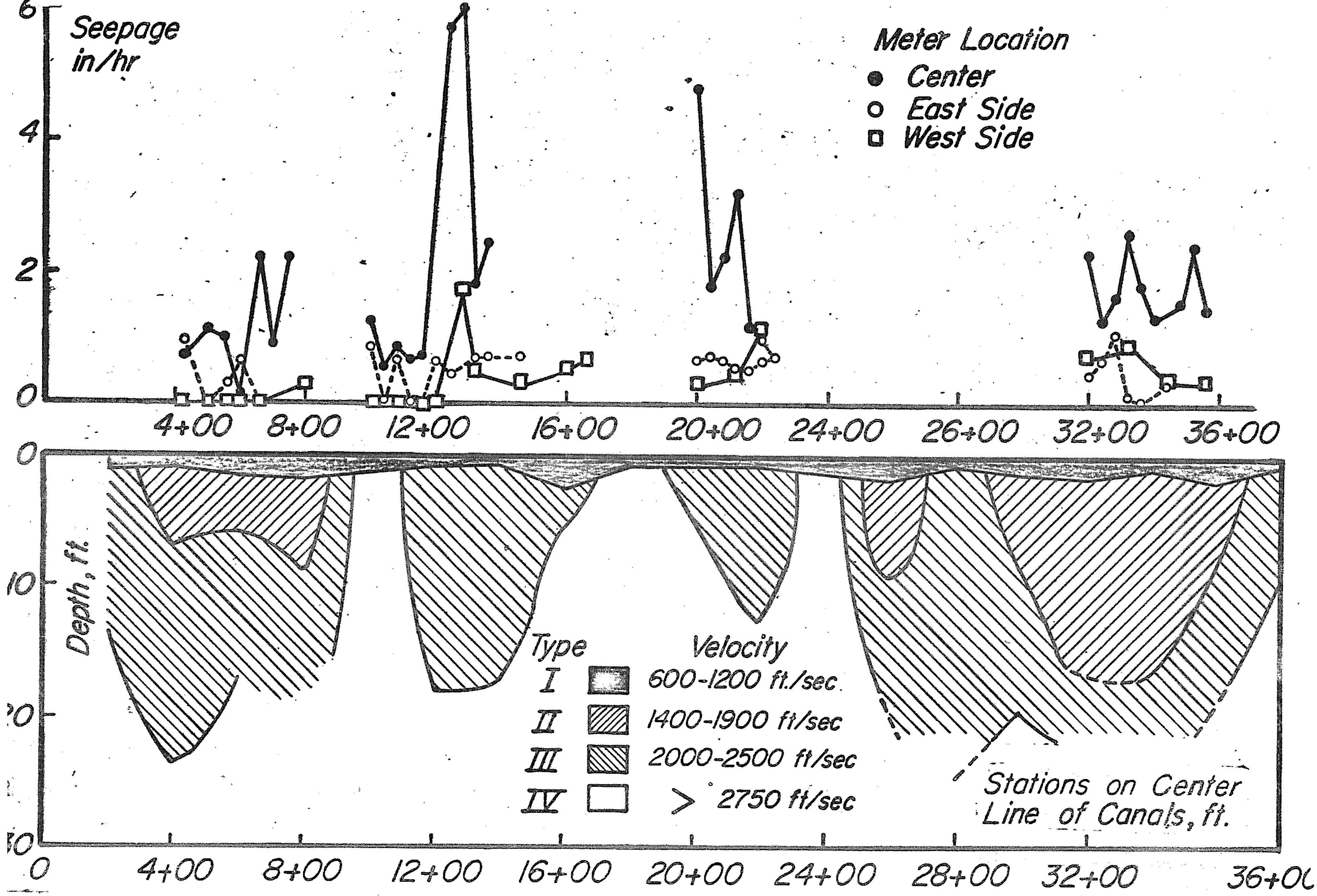


Figure 5. Seepage rates (top) and seismic profile (bottom) for canal section logged.

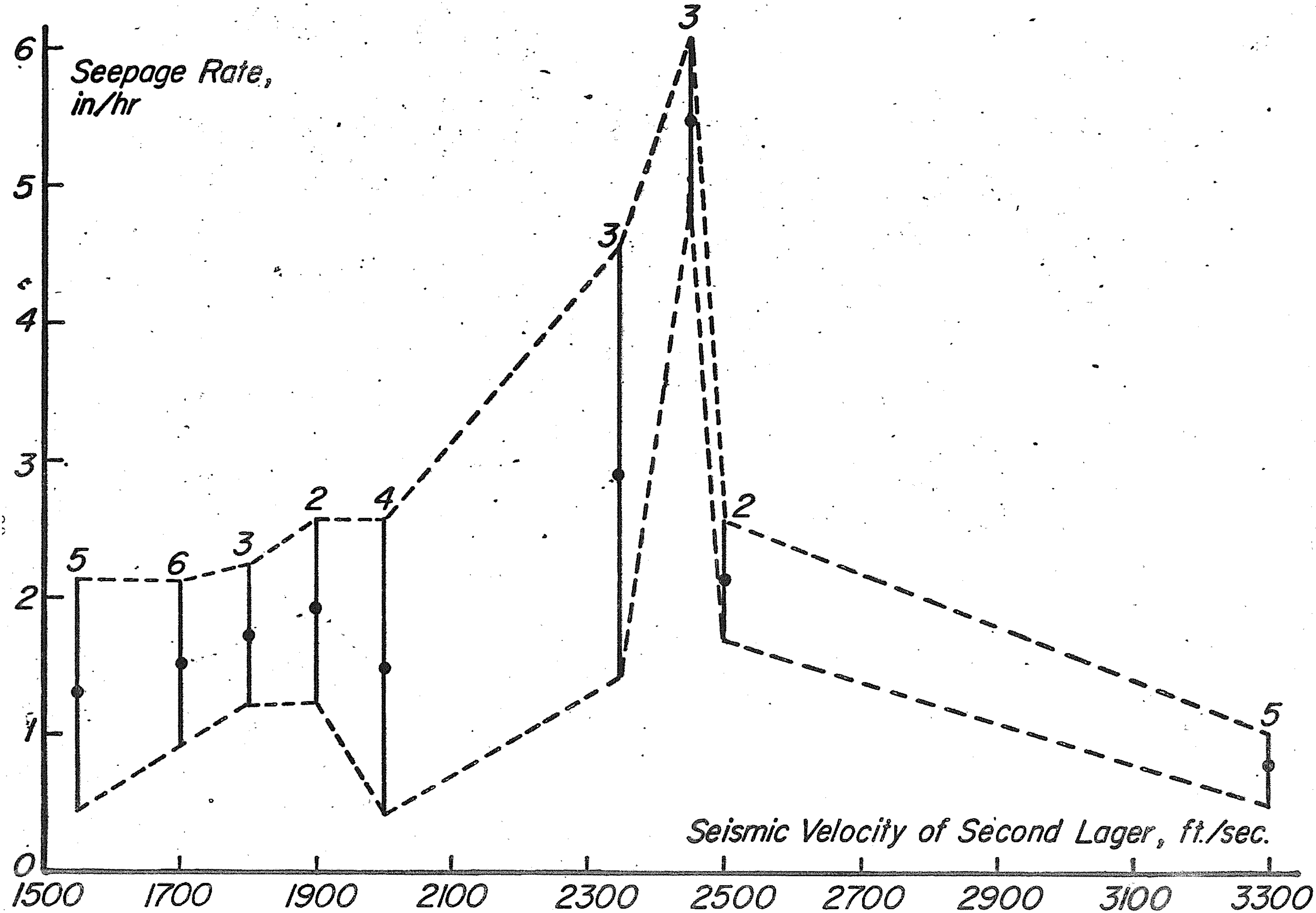


Figure 6. Number of measurements, standard deviation and average seepage versus seismic velocity of second la...

TITLE: SURFACE ENERGY BALANCE IN ARID LANDS AGRICULTURE

LINE PROJECT: SWC 4-gG2

INTRODUCTION:

The amount of water used or lost by various surfaces such as crop surfaces, phreatophyte surfaces, water surfaces, and bare soil surfaces is important in arid lands agriculture. Estimation of the amount of water used by these surfaces requires the measurement and understanding of various atmospheric parameters. Depending upon the method used, these atmospheric parameters have to be related to the actual evaporation to verify the existing theory. Once existing theory has been verified or new theory developed, measurement of the atmospheric parameters will yield estimates of the water used or lost over various undisturbed surfaces.

PROCEDURES:

During the past year, four major experiments have been conducted to determine the magnitude and disposition of the atmospheric parameters as related to evaporation from shallow water surfaces and wet soil surfaces. A rather complete description of these experiments and the instruments used is presented in Surface Energy Balance in Arid Lands Agriculture, Annual Report Fiscal Year 1961, to the Meteorological Department, USAEPG, Fort Huachuca, Arizona, Task No. 3A99-27-005-08. Since the data were not completely analyzed as of the writing of this report, only preliminary results were presented. Consequently, this report will contain only modifications to the instrumentation and the final analysis of the data.

EQUIPMENT CHANGES:

Program. The micrometeorological data handling system printout was reprogrammed in order that a complete line of data could be placed on one IBM punch card. Previously, two punch cards were necessary for one line of data, or a complete printout of 49 channels would require 8 IBM punch cards. The reprogramming would reduce the number of IBM punch cards required to four for a complete printout.

The previous program consisted of a 8-digit date-identifying group followed by a space; 2-digit channel identifier, space; 4-digit channel printout followed by space; channel identifier, space; 4-digit printout, etc. Each line then consisted of a time-date identification group and 10 channel identifiers with their respective printout. Consequently, four typewritten lines were required to list data from 49 channels. Each typewritten line then consisted of 88 characters. The IBM punch card contains only 80 available spaces; therefore, to punch one line of data for 10 channels with the date identifier on an IBM punch card, the spaces between the channel identifier and digital readout were eliminated. The present format of the printout is as follows: 8-digit date-identifying group, space; 2-digit channel identifier followed by a 4-digit channel printout. Each line contains 10 channels with exception of the last line which contains 9 channels; i.e., from channels 41 to 49.

Input cable and plug board. Since the number and types of various micrometeorological elements to be recorded are constantly changing, a plugboard system was deemed necessary to facilitate reprogramming the various cable inputs to the various recording channels. To accomplish this, 11 American Pamcor, 53 series, taper pin blocks with 20 cavities and two 1/2- by 3/4-inch aluminum bars were fastened together with long bolts. The input cables from the experimental field were permanently wired to the backside of the plugboard along with the 40 channel cables from the data handling system. With the present arrangement, any one of the input cables from the lysimeter field may be quite easily connected to any one of the channels of the data handling system with the aid of a short jumper.

Voltage dividers. The original data handling system was capable of transforming various EMF or thermocouple signals into an analog output of a form suitable for tape punch or Flexowriter operation. The analog data then has to be decoded or transformed into the standard units for further analysis. Approximately one-half of our previous IBM analysis was utilized in transforming the analog outputs into standard units. This was time consuming and costly; furthermore, the data could not be easily inspected at the Laboratory until it had been received from IBM analysis. This meant a delay from three to six months. To remedy this situation, fifteen 2000-ohm, 10-turn Helipots were installed in the lysimeter field in such a fashion that the inputs from the lysimeter field could be scaled down so that the analog output from the data handling system was in standard units, instead of the analog as previous. The lead wires from the voltage dividers were fixed so they could be used in place of a jumper to connect the cable inputs to the various channels. This method proved very effective for transducers which have different calibration curves, such as the net radiometers, the solar radiometers, and the heat-flow transducers. This method was not applied to the thermocouple inputs because of the reduced accuracy that would have resulted and also, because all the thermocouple inputs can be decoded with the aid of one equation or slide rule.

Wind-recording system. The original wind-recording system was modified to include nine Veeder-Root counters with electrical readout and reset. The counters are now activated by sensitive intermediate relays; the sensitive relays being activated, in turn, by the contact closures of the anemometers. To accomplish the addition of the three extra Veeder-Root counters, the main data handling system had to be reprogrammed so that the additional counters could be read out.

After the counters have been used for a considerable period of time, the shims within the counting wheels wear sufficiently to allow for poor contact closure in the readout mechanism. The main data handling system is so designed that when an open circuit is encountered in the printout cycle, the printout cycle will be stopped. This has happened several times during counter readout;

therefore, the wind system was further modified with the addition of a stepping switch connected to each digit of the counters. After the counting cycle had been stopped for a period of 15 seconds, a time-delay relay is energized, causing the stepping switch to sequentially interrogate the counters from back to front, automatically closing the open circuits with a space impulse. When the open circuit is encountered and closed with a space impulse, the main system will continue the printout cycle. A light on the front of the system enables one to determine if there has been an open circuit during the previous recording cycles. By investigating the data, one can determine which counter was faulty and by comparing it with the data from the other counters, can determine which digit of the counter was causing the trouble.

Installation of the field cables. Four additional thermocouple-type cables containing fourteen pairs of copper-constantan thermocouple wires were installed in the lysimeter field. These cables were installed between each of the three lysimeters and the central mast to the junction box. The lysimeter and the central mast end of the cables were fitted with a cable-to-cable-type connector so that the sensor end of the connector may be readily rewired to facilitate measuring of various meteorological factors. The cables were buried at a depth of 12 inches. With this semi-permanent type of installation, the field may be readily cultivated without disturbing any of the sensing cables.

Soil heat-flow transducers. Originally Beckman & Whitley heat-flow transducers, model No. ST201-1, were utilized. The transducers were 3-3/8 inches long, 1-1/8 inch wide, and 3/64 inch thick. These transducers had been previously used by other personnel before being used in our work. Some of the heat-flow transducers were coming apart. These were again clamped together and resealed. A comparative check indicated that the calibration factors of the heat-flow transducers had been changed. The heat-flow transducers were considered unsuitable for future research because of the separation of the outer surfaces and also because of discontinuity of some of the thermocouple circuits; therefore, five additional thermal transducers were purchased from National Instruments Laboratory, 828 Evarts Street, N.E., Washington 18, D.C, Model No. HF-2. These transducers are approximately 50 mm in diameter, 3.3 mm thick. They are constructed of polyvinal chloride, which has a thermoconductivity of 0.033 cal min^{-1} cm^{-1} $^{o}C^{-1}$. They have the internal resistance of 100 ohms and have a calibration constant of approximately 50 mv cal^{-1} cm^{-2} min^{-1}. The heat-flow transducers were calibrated at 20C and have a temperature coefficient of approximately 1 percent per 10C.

RESULTS AND DISCUSSION

As indicated before, the preliminary results of the four experiments were reported in the Report to the Army; however, since that time the final evaluation of the data with respect to the energy balance components has been completed.

The hourly distribution of the energy balance components along with windspeed and direction for each day of the four experiments are presented in Figures 1 to 15. Although the hourly distribution of these components is important and can be scrutinized in detail, the following major facts are evident:

(1) In all cases net radiation was negative during the nocturnal hours and positive during the daylight hours as would be expected.

(2) The evaporative flux (LE) was always negative.

(3) A considerable amount of evaporation was noted during the nocturnal hours even after the soil surface had changed color and become dry.

(4) The S + S' or W term, as the case may be, was positive during the nocturnal hours and negative during the early part of the daylight hours. In some cases this term changed from positive to negative during the late afternoon.

(5) The sensible heat flux to the air term (A) was generally zero during the nocturnal hours in Little Mud 1 (LM1) and positive during the daylight hours when the soil surface was wet, for instance 14 April, 1961; however, this picture reversed when the soil surface became dryer in that A was negative during both the daylight and nocturnal hours. In the case of Little Splash 2 (LS2), A was positive during both the nocturnal and daylight hours indicating that energy was derived from the air in the form of sensible heat. In the case of Big Splash 1 (BS1), the sign of the

sensible heat flux to the air term (A) was negative during the nocturnal and daylight hours. This is a contrast to LS2, or a contrast between the extended shallow water and the isolated shallow water surface. In the case of Big Mud 1 (BM1), when the soil surface was wet, A was positive during the nocturnal hours and negative during the daylight hours. This is again a contrast to the conditions prevailing in LM1.

(6) In all cases of readily evaporating surfaces, a secondary maximum and the actual amount of evaporation appeared to be correlated with increasing windspeed when the energy inputs were similar. To emphasize this point, the evaporative flux (LE) on 26 April was subtracted from the evaporative flux on 25 April and plotted against the difference in windspeed, that is, wind on 25 April minus wind on 26 April. The hourly points thus obtained are shown in Figure 16. These days were quite similar with respect to energy input and underlying surfaces; therefore, a direct comparison is feasible. Although there is considerable scatter among the hourly points in Figure 16, there is a definite indication that the difference in the evaporative flux is correlated with the difference in windspeed.

To facilitate the direct comparison of the various components of the energy balance equation, solar radiation and average wind movement, the daily values for each day and for each lysimeter of all experiments are presented in Table 1. One can see a quite close agreement between the measurements made in and over each lysimeter.

(1) In comparing Little Mud and Big Mud, the soil surface appeared to dry quicker in LM than in BM as one would expect from an isolated wet surface in a large dry area.

(2) In the case of LM, energy was derived from the air during the first day when the soil surface was wet. This term changed sign after the soil surface became dry and increased in magnitude.

(3) The sensible heat flux to the air term (A) was negative at all times in BM and also increased in magnitude as the soil surface became dryer.

(4) Again, when the soil surface was wet, energy was derived from the underlying surface in both LM and BM.

(5) As the soil surface became dryer, the sign of the term ($S + S'$) changed and increased in magnitude indicating that more energy was utilized in heating the underlying soil.

(6) The evaporative flux (LE) decreased as time progressed. Consequently, the soil surface changed in color and became heated, thus resulting in a decreasing net radiation with time and increase in the negative direction of $S + S'$ and A.

(7) In comparing Little Splash 2 and Big Splash 1, one notes that the evaporative flux is always greater in the case of the isolated shallow water surface than in the case of the extended shallow water surface.

(8) In both experiments for similar energy inputs, increased evaporative flux was associated with increased wind movement.

(9) In the case of LS2, the term S + W was always positive, while in the case of BS1, the S + W term was positive and negative with the positive term being associated with the greater evaporative flux.

(10) The sensible heat flux to the air term (A) was always positive in LS2 and always negative in BS1, indicating that for the isolated shallow water surface, energy was being continually derived from the overlying air while energy was utilized in heating the air in the case of the extended shallow water surface.

(11) It is very difficult to make any direct comparison between LM1 and LS2 since the early part of both LM1 and LS2 was cloudy; however, 14 April and 18 April are similar with respect to solar radiation, but the average wind movement is somewhat greater on 18 April. One notices that a greater evaporative flux existed on 18 April as compared to 14 April. This may be explained by the difference in wind movement and also, in availability of moisture.

(12) Some very interesting comparisons can be made between BS1 and BM1. In both experiments, a secondary maximum of evaporative flux tended to be associated with an increase in windspeed. When similar radiation inputs and wind movement existed, a larger evaporative flux was measured over the wet soil surface than over the extended shallow water surface.

(13) In both experiments the S + W or S' term, as the case may be, was positive when the larger evaporative rates existed; however, this term became negative with the lesser evaporative

rates, and increased in the negative direction when the soil surface became dry (BM1).

(14) The most noticeable fact is that the sensible heat flux to the air term was negative in all cases reported in both experiments. This indicates that with an area as small as 6,700 m^2, no energy was derived from the overlying air mass. This is in contrast to the cases of the isolated wet surfaces, LS2 and LM1; however, it is quite significant when considering the energy balance over cropped areas of moderate size.

PERSONNEL: L. J. Fritschen, C. H. M. van Bavel, and R. J. Reginato.

Table 1.--Daily totals of the energy balance components for each lysimeter, average windspeed and solar radiation.

LITTLE MUD 1

		U_{155}	R_{su}	R_n	LE	S+S'	A
		cm sec^{-1}	←		ly day^{-1}		→
04/14/61	Ly I			351	-448	+28	+69
	Ly II			360	-462	+35	+67
	Ly III			340	-441	+21	+80
	Ave.	253	694	350	-450	+28	+72
04/15/61	Ly I			286	-178	-16	-92
	Ly II			296	-182	-29	-85
	Ly III			280	-187	-22	-71
	Ave.	187	706	287	-182	-22	-82
04/16/61	Ly I			276	-110	-34	-132
	Ly II			284	-110	-63	-111
	Ly III			267	-110	-56	-101
	Ave.	152	692	276	-110	-51	-114

LITTLE SPLASH 2

		U_{155}	R_{su}	R_n	LE	S+W	A
		cm sec^{-1}	←		ly day^{-1}		→
04/18/61	Ly I			458	-680	+19	+203
	Ly II			452	-674	+21	+201
	Ly III			449	-660	+9	+202
	Ave.	337	687	453	-671	+16	+202
04/19/61	Ly I			404	-607	+22	+181
	Ly II			403	-603	+24	+176
	Ly III			403	-603	+15	+185
	Ave.		619	403	-605	+20	+181
04/20/61	Ly I			419	-500	+28	+53
	Ly II			400	-482	+31	+51
	Ly III			410	-492	+13	+69
	Ave.		679	410	-491	+24	+57

Table 1.--Continued

LITTLE SPLASH 2

		U_{155}	R_{su}	R_n	LE	S+W	A
		cm sec^{-1}	←		ly day^{-1}		→
04/21/61	Ly I			453	-521	+9	+59
	Ly II			450	-506	+8	+48
	Ly III			442	-509	-1	+68
	Ave.	217	721	448	-512	+6	+59
04/22/61	Ly I			444	-570	+11	+115
	Ly II			424	-567	+16	+127
	Ly III			433	-559	+2	+124
	Ave.	252	711	434	-565	+9	+122

BIG SPLASH 1

		U_{150}	R_{su}	R_n	LE	S+W	A
		cm sec^{-1}	←		ly day^{-1}		→
04/25/61	Ly I			417	-331	+6	-92
	Ly III			424	-371	+1	-54
	Ave.	209	733	421	-351	+4	-73
04/26/61	Ly I			419	-290	-21	-108
	Ly III			417	-325	-33	-59
	Ave.	153	732	418	-308	-27	-84

BIG MUD 1

		U_{155}	R_{su}	R_n	LE	S+S'	A
		cm sec^{-1}	←		ly day^{-1}		→
04/28/61	Ly I			383	-343	+5	-45
	Ly III			375	-352	+10	-33
	Ave.	151	713	379	-348	+7	-38
04/29/61	Ly I			409	-418	+9	0
	Ly III			400	-408	+6	+2
	Ave.	183	734	404	-413	+8	+1

Table 1.--Continued

BIG MUD 1

		U_{155}	R_{su}	R_n	LE	S+S'	A
		cm sec^{-1}	←		ly day^{-1}		→
04/30/61	Ly I			408	-377	-10	-21
	Ly III			390	-337	-11	-42
	Ave.	160	723	399	-357	-10	-32
05/01/61	Ly I			374	-293	-36	-45
	Ly III			348	-245	-13	-90
	Ave.	163	722	361	-269	-24	-68
05/02/61	Ly I			337	-251	-46	-40
	Ly III			320	-199	-23	-98
	Ave.	233	723	328	-225	-34	-69

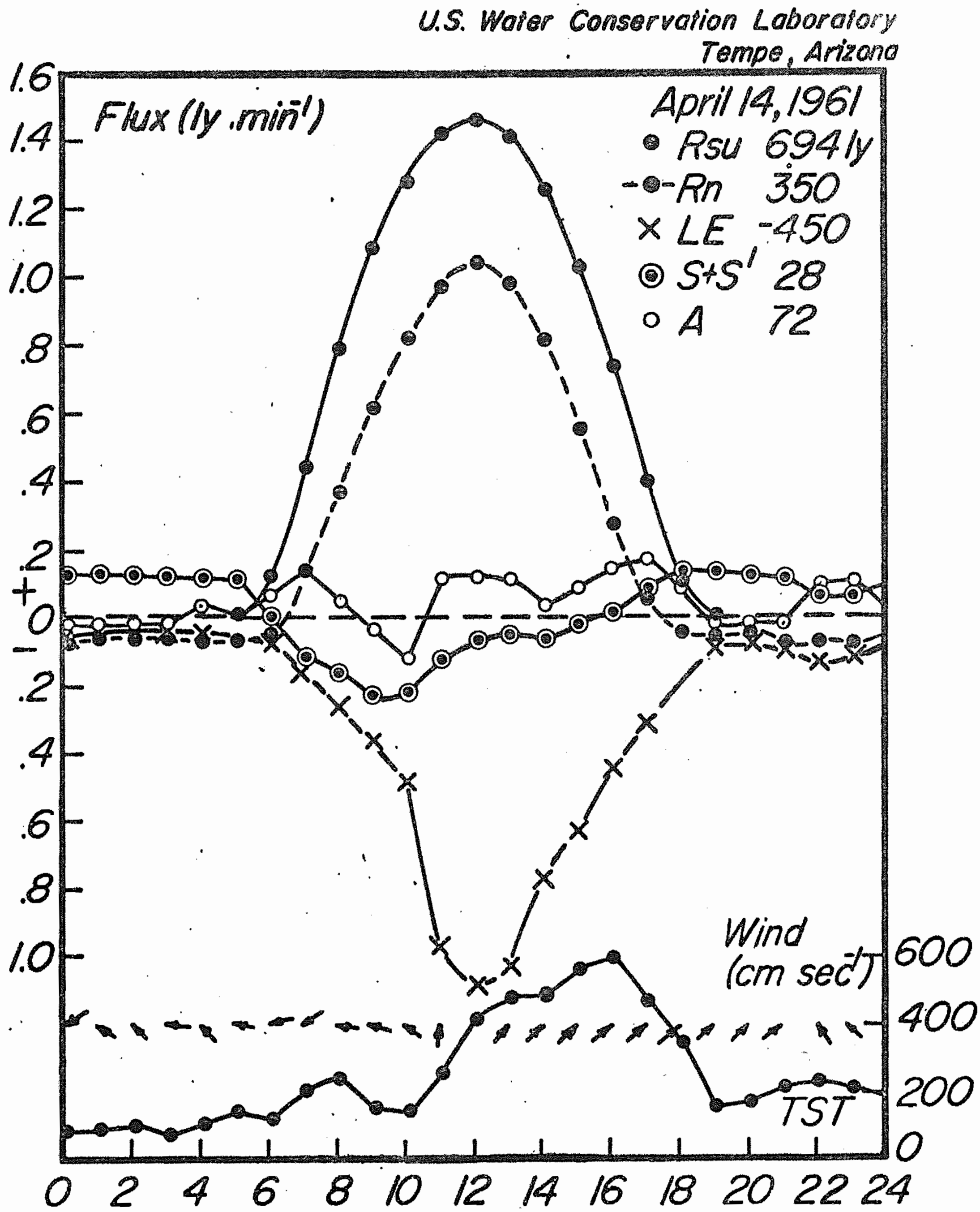


Figure 1.--Hourly values of solar and net radiation, soil heat flow, evaporative flux, sensible heat to the air, windspeed and direction.

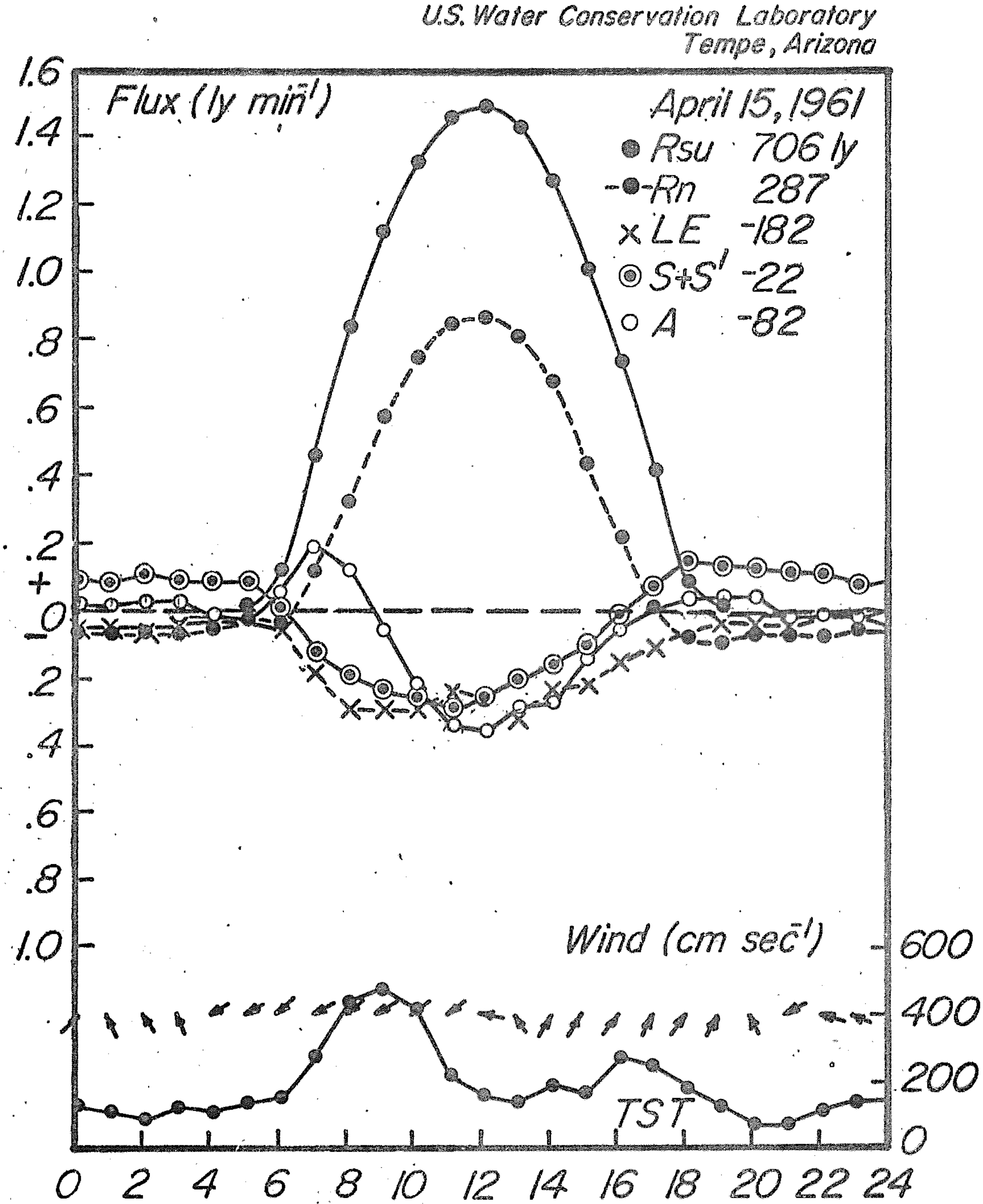


Figure 2.--Hourly values of solar and net radiation, soil heat flow, evaporative flux, sensible heat to the air, windspeed and direction.

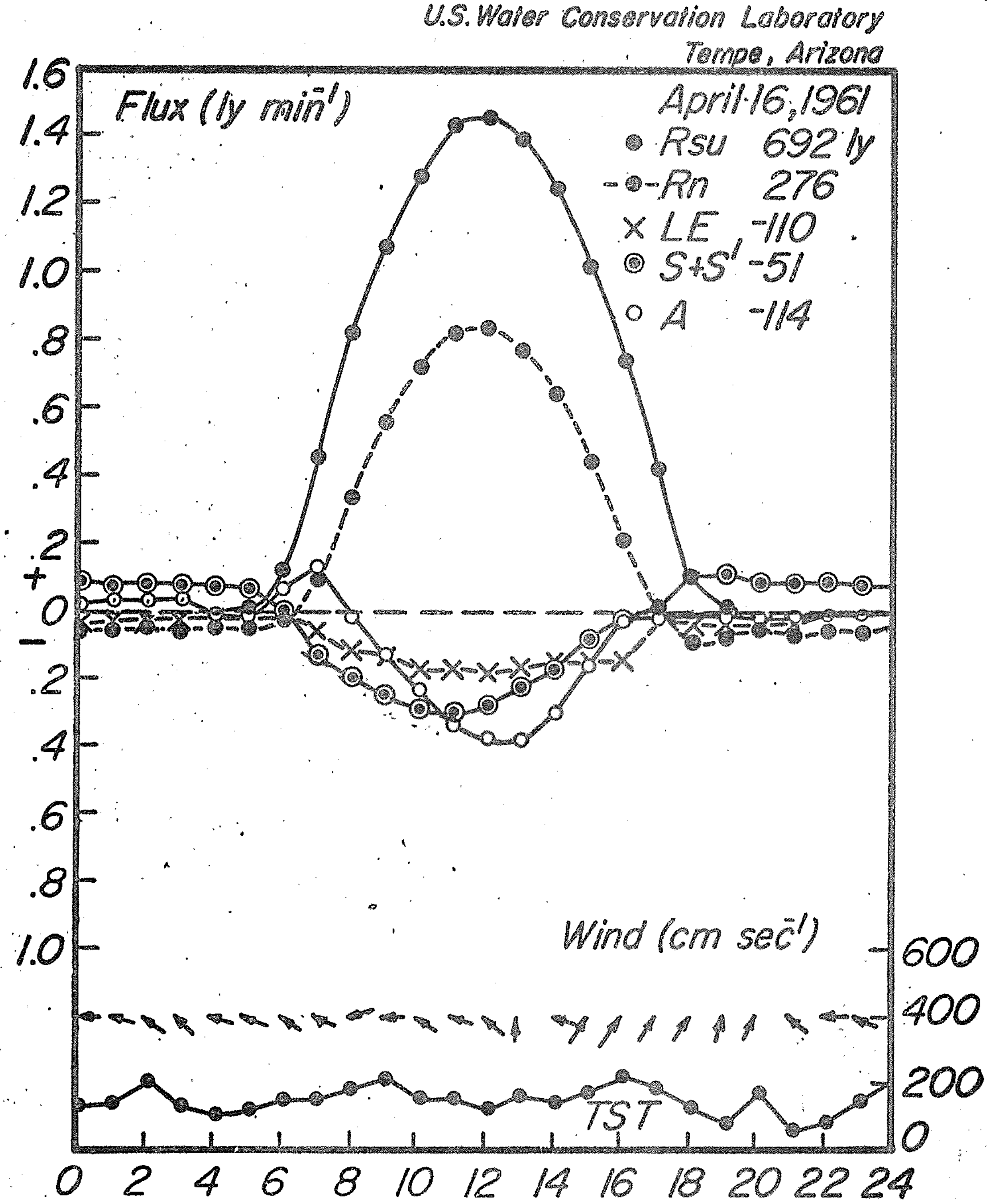


Figure 3.--Hourly values of solar and net radiation, soil heat flow, evaporative flux, sensible heat to the air, windspeed and direction.

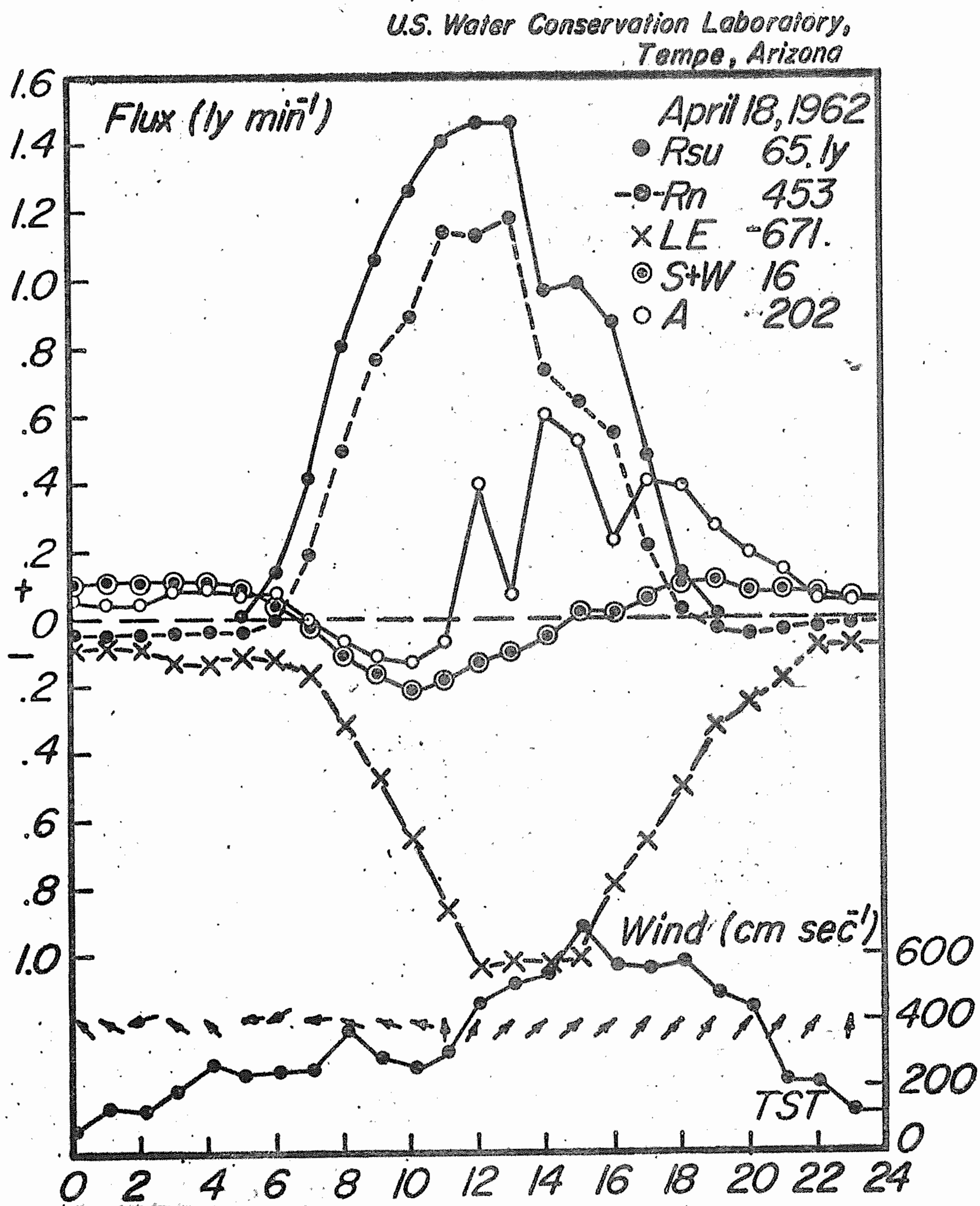


Figure 4.--Hourly values of solar and net radiation, soil heat flow, evaporative flux, sensible heat to the air, windspeed and direction.

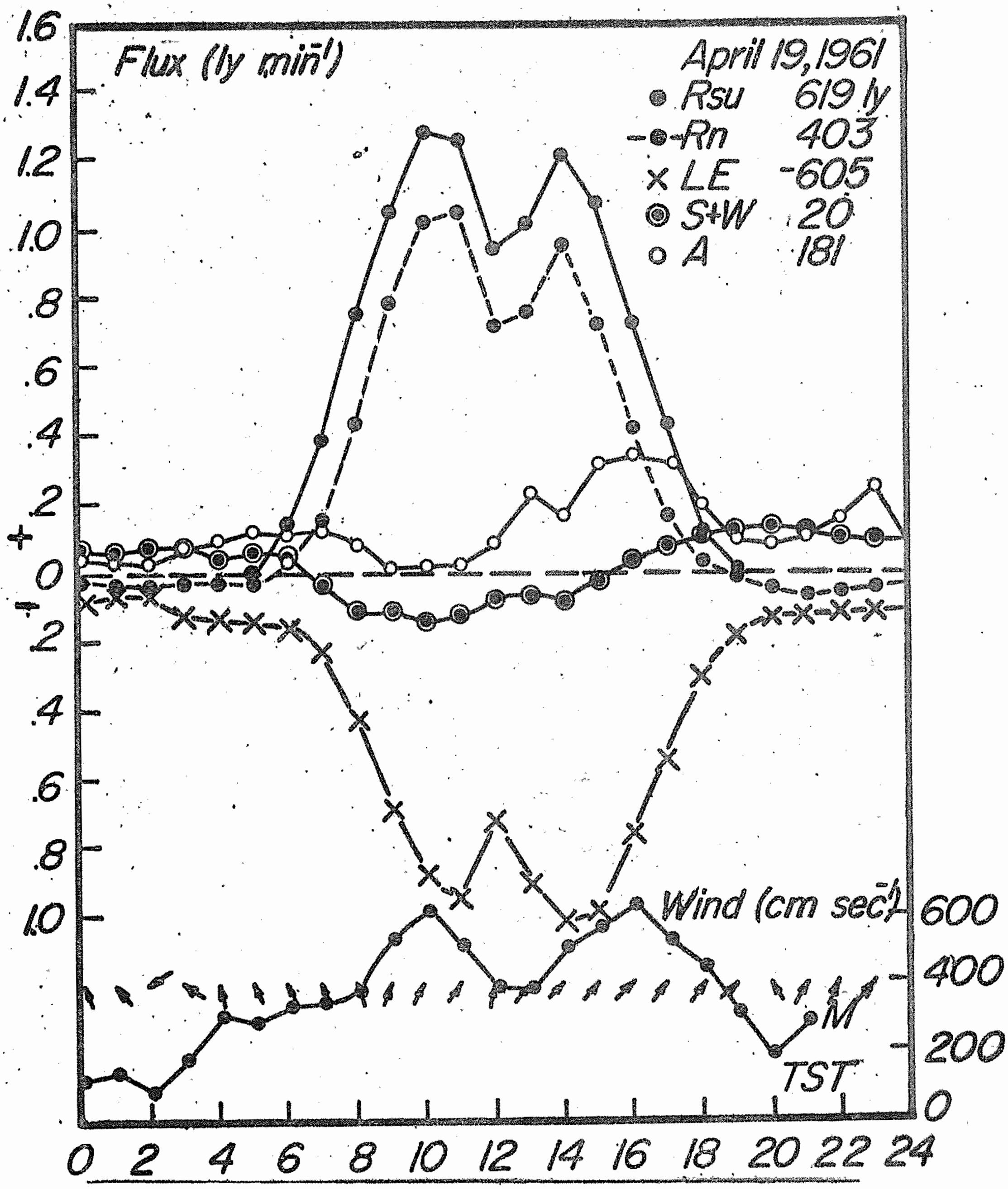


Figure 5.--Hourly values of solar and net radiation, soil heat flow, evaporative flux, sensible heat to the air, windspeed and direction.

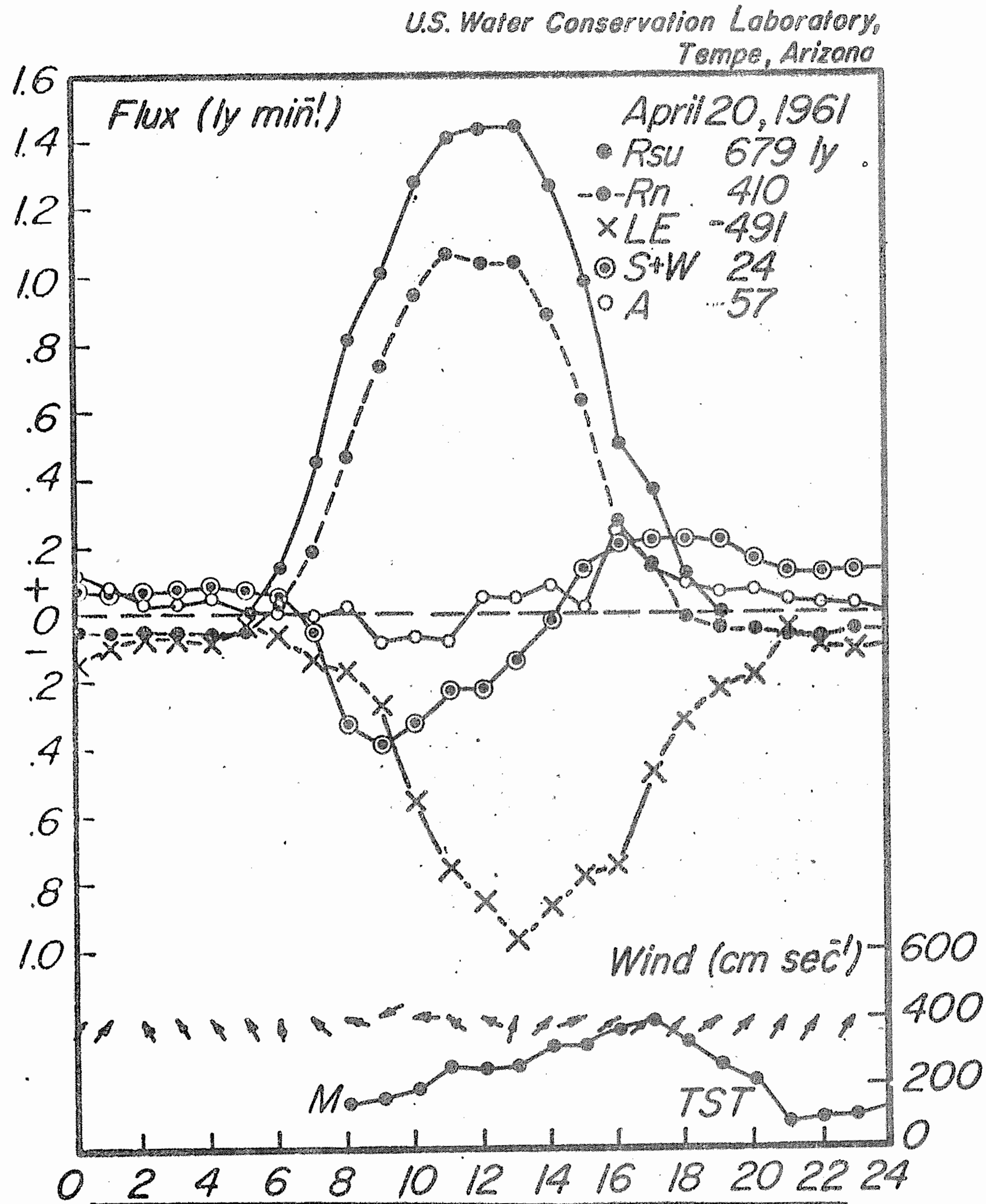


Figure 6.--Hourly values of solar and net radiation, soil heat flow, evaporative flux, sensible heat to the air, windspeed and direction.

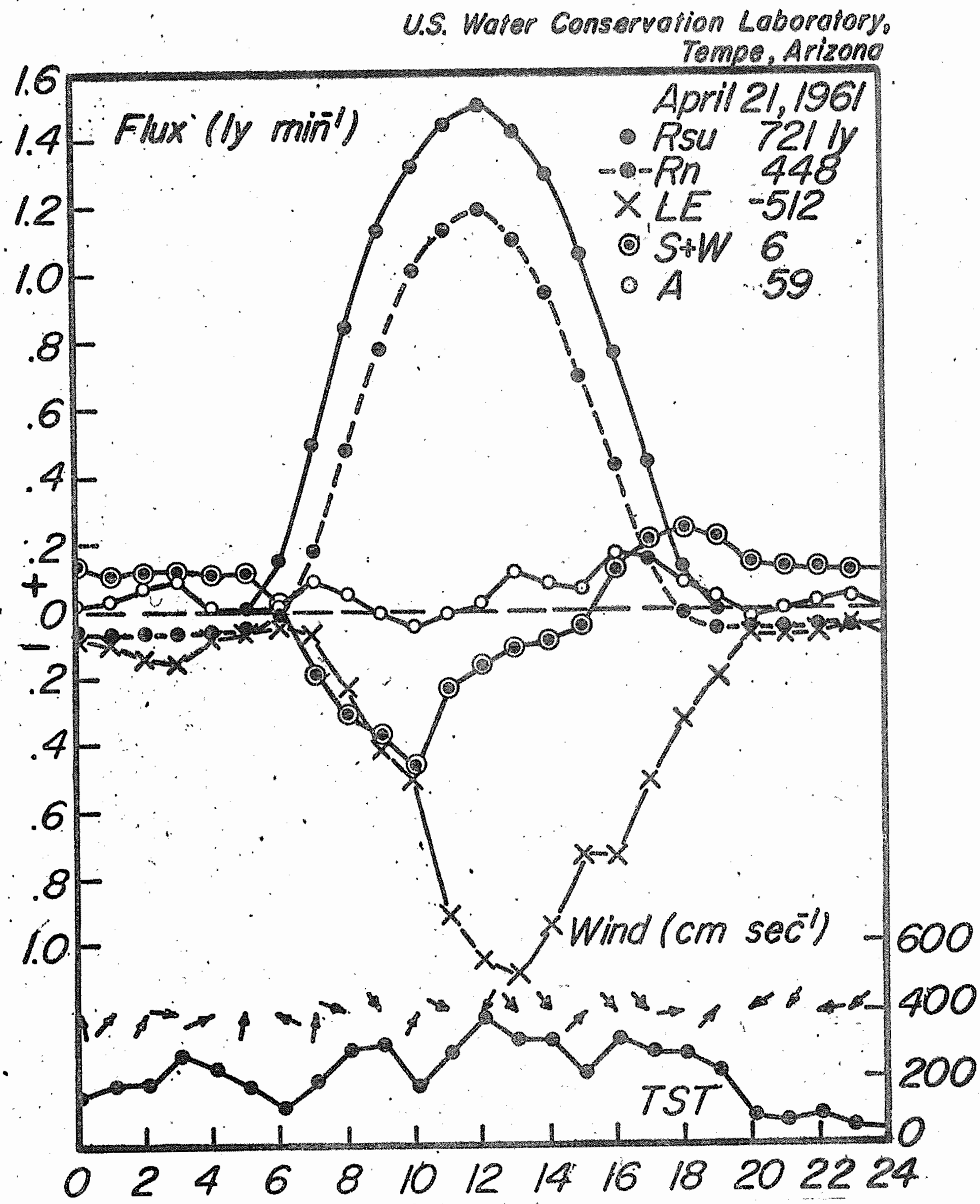


Figure 7.--Hourly values of solar and net radiation, soil heat flow, evaporative flux, sensible heat to the air, windspeed and direction.

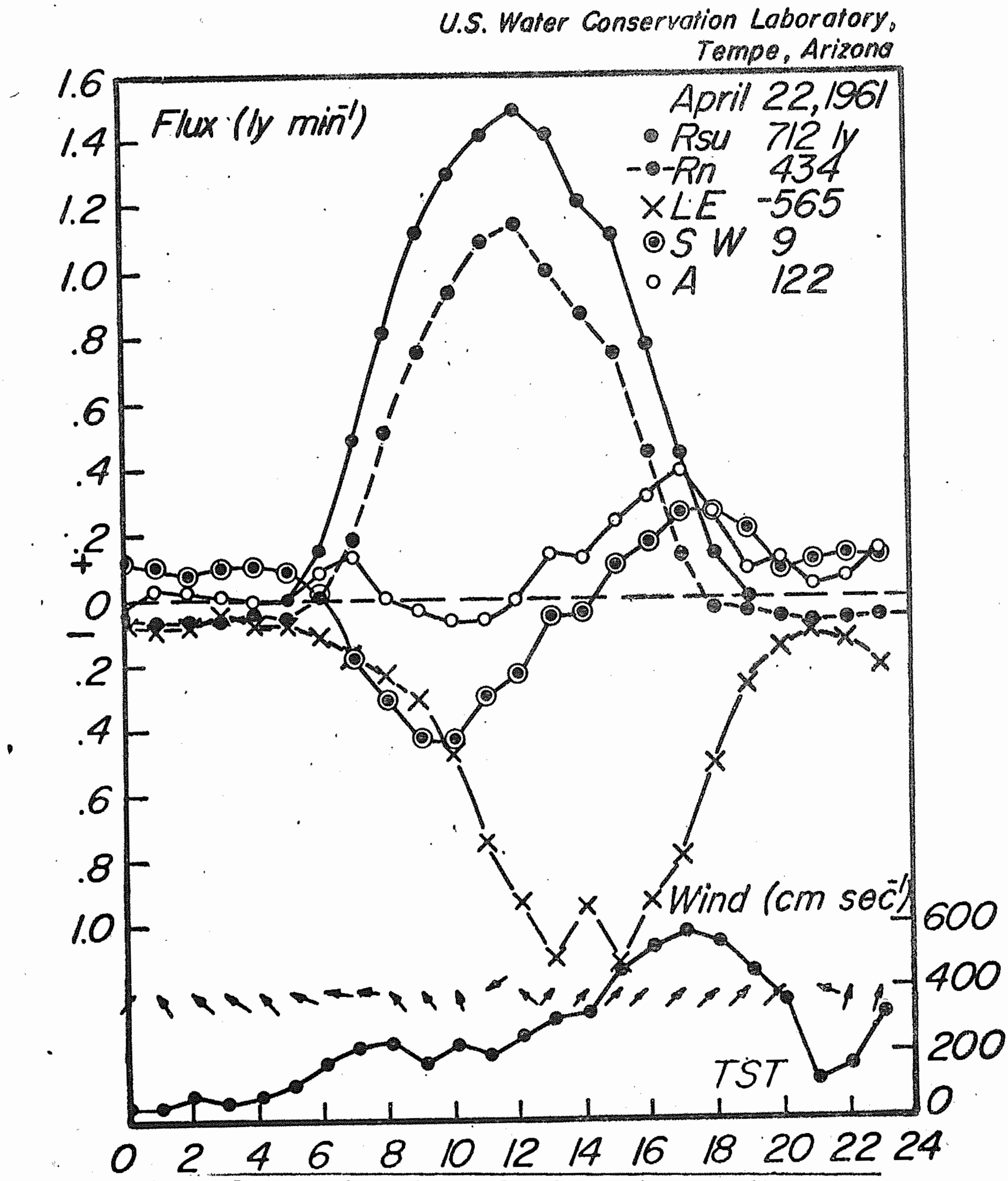


Figure 8.--Hourly values of solar and net radiation, soil heat flow, evaporative flux, sensible heat to the air, windspeed and direction.

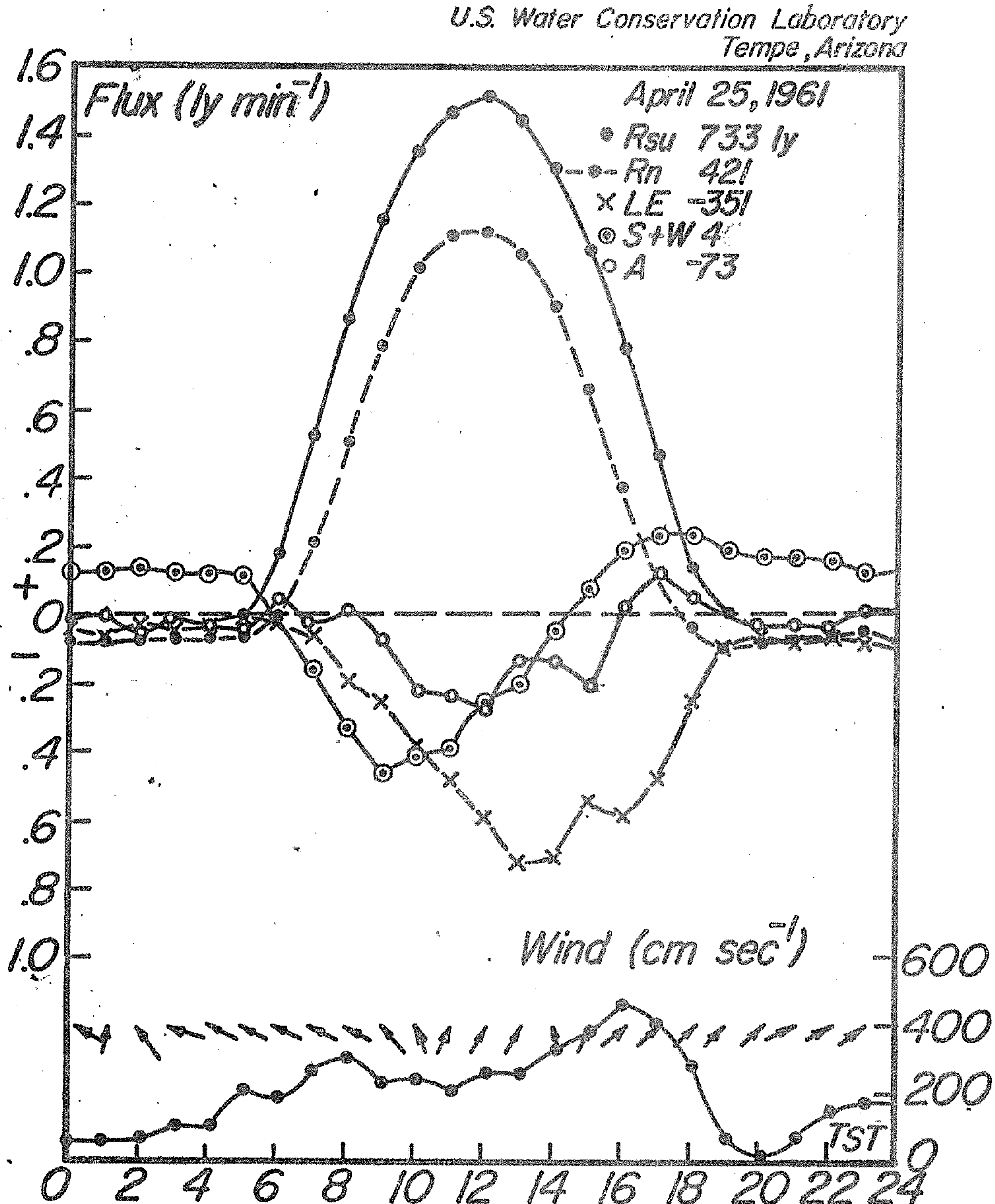


Figure 9.--Hourly values of solar and net radiation, soil heat flow, evaporative flux, sensible heat to the air, windspeed and direction.

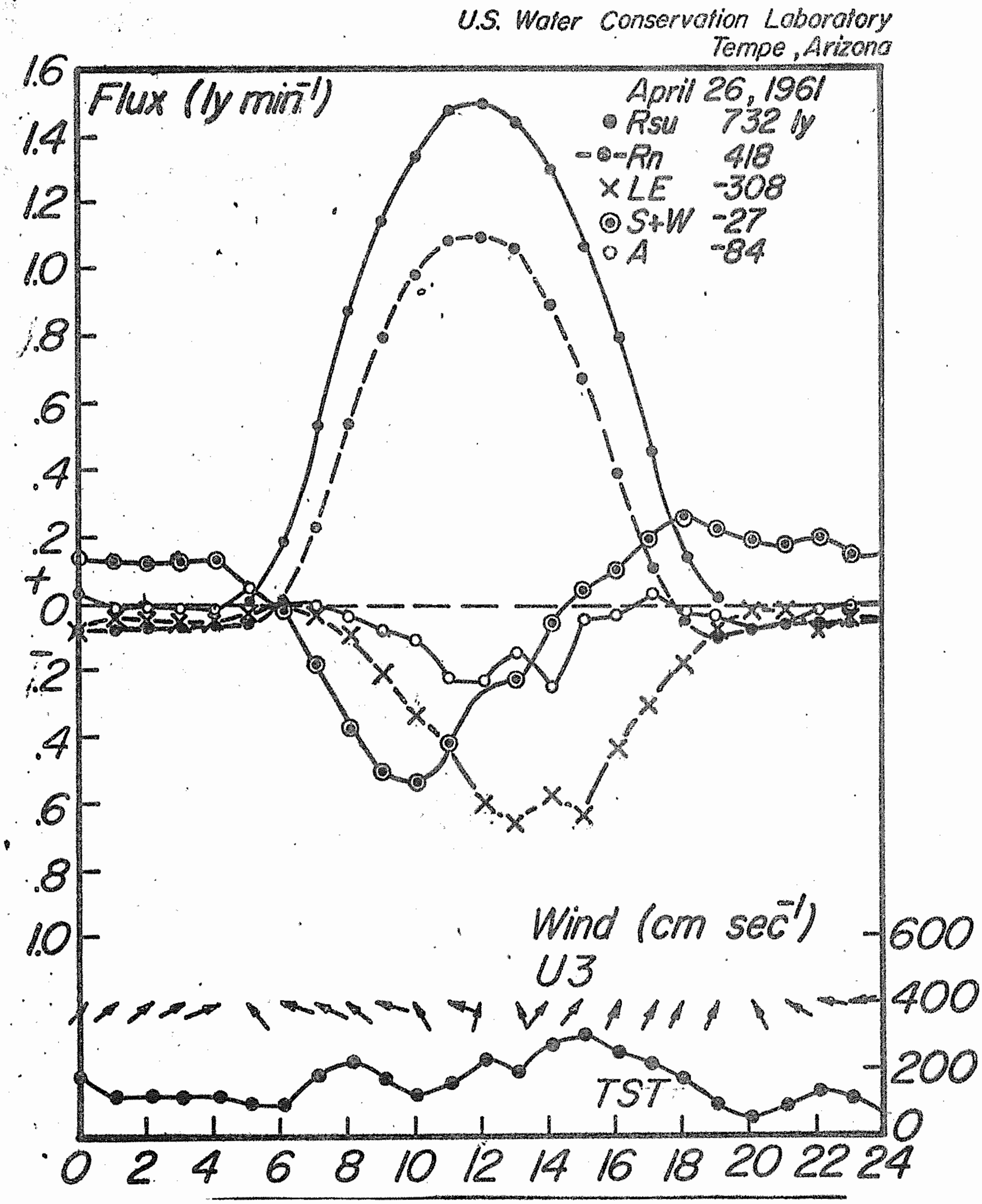


Figure 10.--Hourly values of solar and net radiation, soil heat flow, evaporative flux, sensible heat to the air, windspeed and direction.

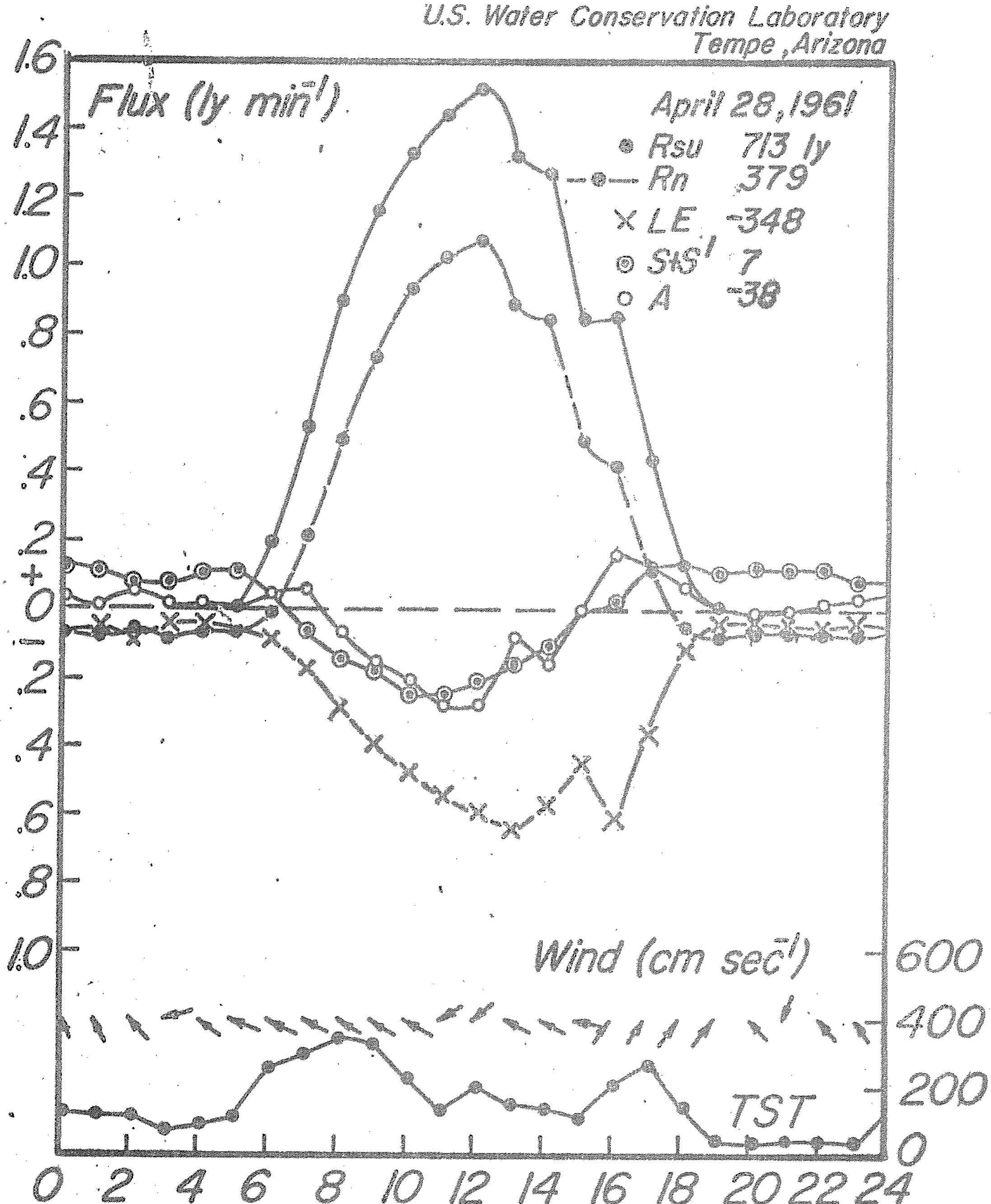


Figure 11.--Hourly values of solar and net radiation, soil heat flow, evaporative flux, sensible heat to the air, windspeed and direction.

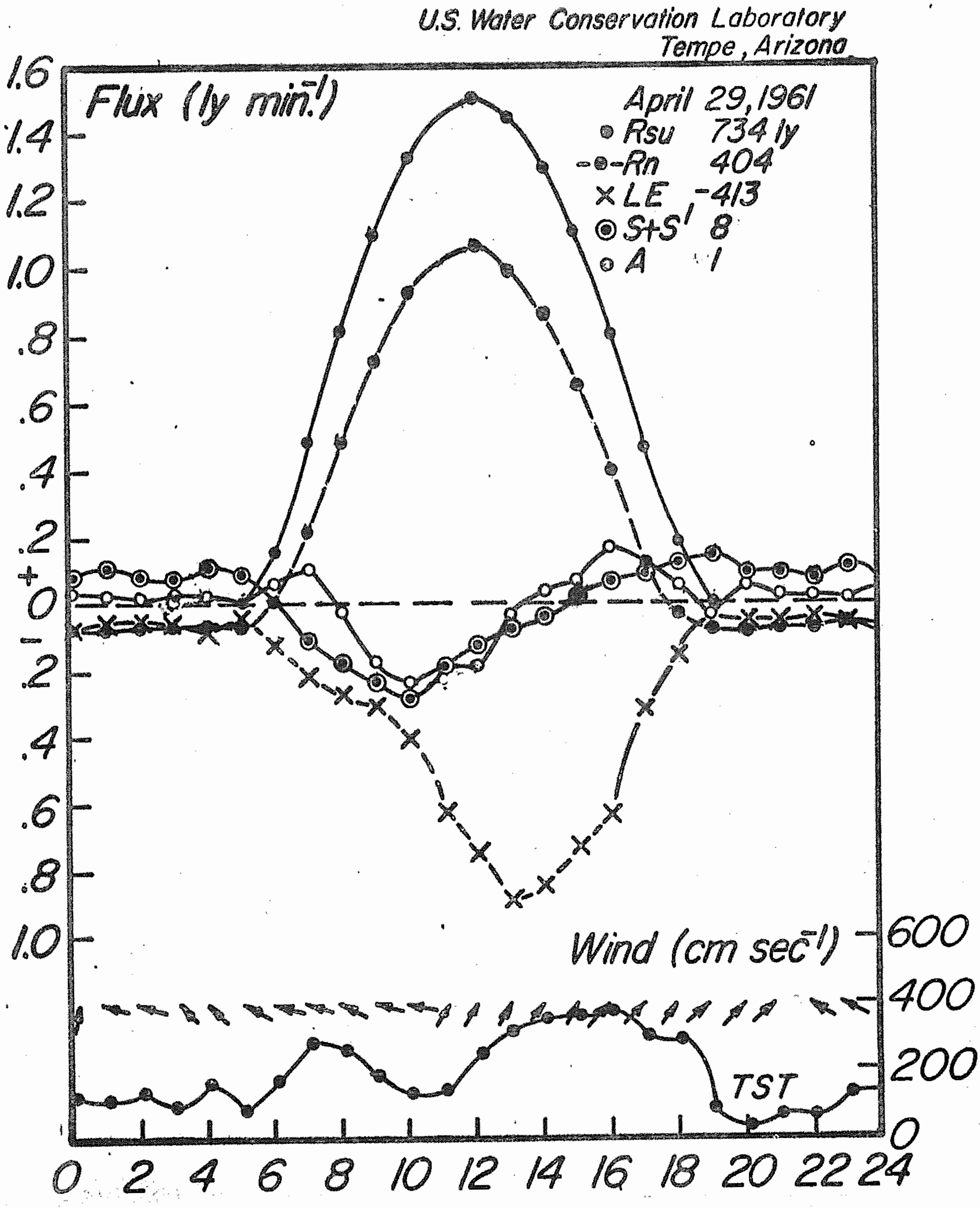


Figure 12.--Hourly values of solar and net radiation, soil heat flow, evaporative flux, sensible heat to the air, windspeed and direction.

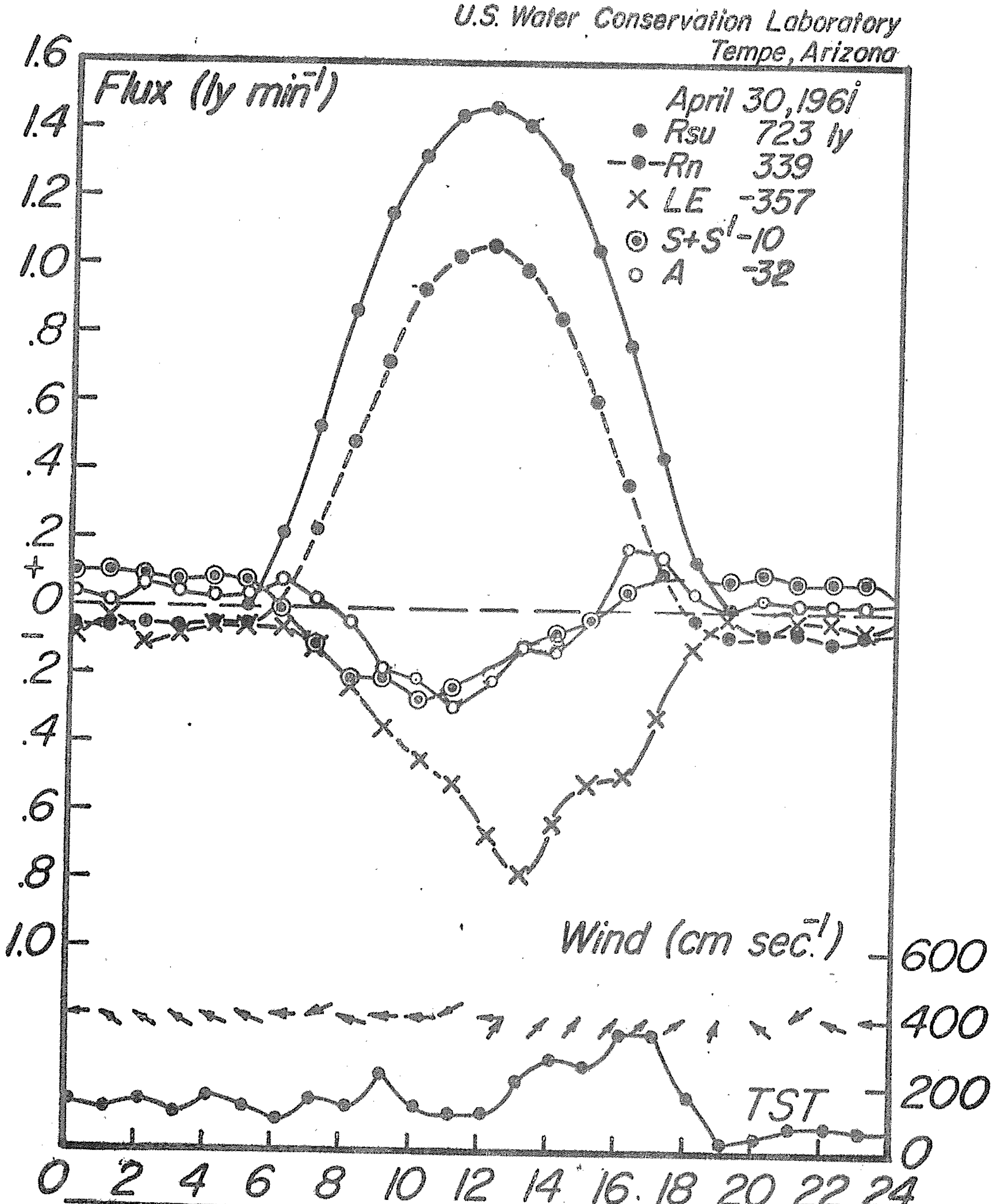


Figure 13.--Hourly values of solar and net radiation, soil heat flow, evaporative flux, sensible heat to the air, windspeed and direction.

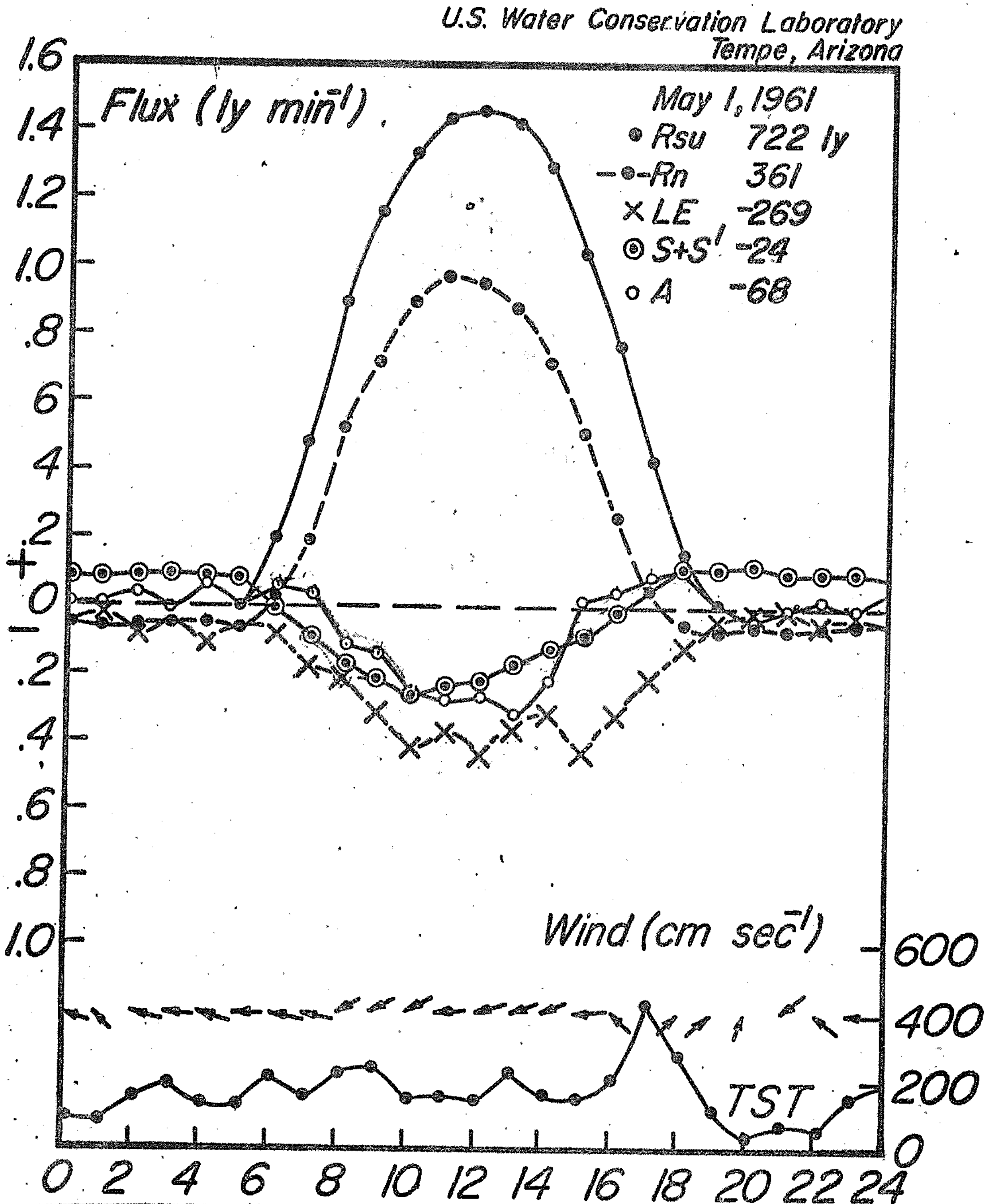


Figure 14.--Hourly values of solar and net radiation, soil heat flow, evaporative flux, sensible heat to the air, windspeed and direction.

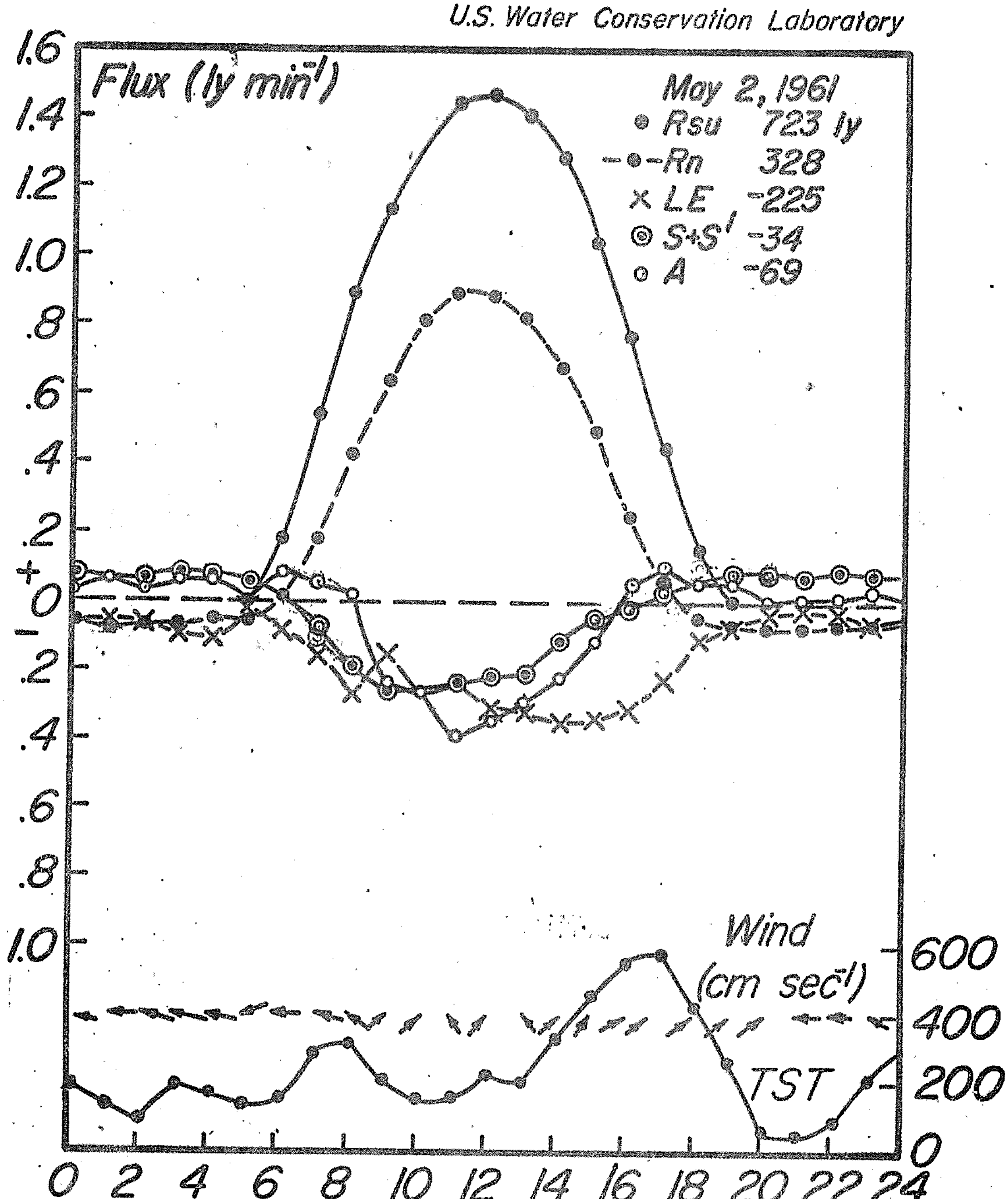


Figure 15.--Hourly values of solar and net radiation, soil heat flow, evaporative flux, sensible heat to the air, windspeed and direction.

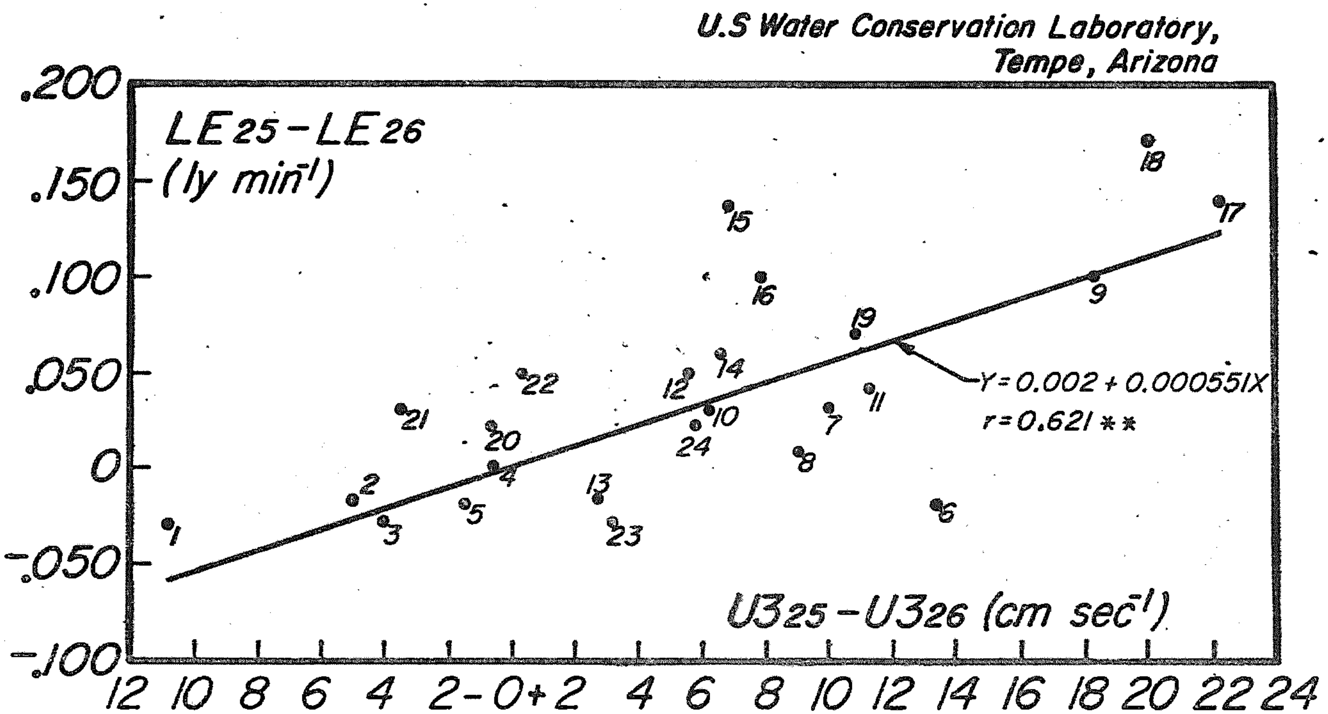


Figure 16.--Hourly values, differences in evaporative flux versus differences in windspeed.

TITLE: CALIBRATION AND EVALUATION OF NET RADIOMETERS

LINE PROJECT: SWC 4-gG2 CODE: Ariz.-WCL-6

This year's research on net radiation has been reported in Surface Energy Balance in Arid Lands Agriculture, Annual Report Fiscal Year 1961 to the Meteorological Department, USAEPG, Fort Huachuca, Arizona, Task No. 3A99-27-005-08, pages 48 to 71.

PERSONNEL: Leo J. Fritschen

TITLE: APPLICATION OF HEXADECANOL - OCTADECANOL MONOFILMS TO SMALL PONDS

LINE PROJECT: SWC 4-gG 2 CODE NO.: Ariz.- WCL-9

INTRODUCTION:

See Annual Report - 1960.

PROCEDURE:

See Annual Report - 1960.

Personnel of the Soil and Water Conservation Research Division, Tucson, Arizona, agreed to obtain data from three ponds near Tombstone, Arizona. Laboratory personnel obtained data from two ponds near Pine, Arizona. Personnel of the Kern County Land and Cattle Company, Bakersfield, California, agreed to obtain data from four ponds near Seligman, Arizona, and three ponds in New Mexico. Personnel of the Bureau of Land Management, Reno, Nevada, agreed to obtain data from a pond near Caliente, Nevada. Procedures were to be the same as those used in 1960.

RESULTS AND DISCUSSION:

Considerable difficulty was encountered in obtaining data from the field because of drought, changes in cooperator personnel, and program changes by the cooperators. Film pressure measurements were made immediately prior to refilling the rafts. The lowest and highest readings are reported.

Tombstone Ponds: Stockponds in the Tombstone area remained dry for the second consecutive year and no data were obtained.

Seligman Ponds: These ponds remained dry and no data were obtained.

Pine Ponds: Rafts were placed on these ponds on 4-29-61, and the first readings were taken 20 minutes after they were installed. The ponds were nearly dry after 5-12-61 and observations ceased.

Date	Wind Speed	Water Temp.	Air Temp.	Film Pressure	
				Upper Pond	Lower Pond
	mph	°F	°F	dynes/cm	dynes/cm
4-29-61	7-8	--	--	10-35	0-5
5-6-61	8-10	62	50	5-35	5-20
5-12-61	15-20	70	74	10-35	20-35

Caliente Pond: The raft was installed on 5-17-61.

Date	Wind Speed	Water Temp.	Air Temp.	Film Pressure
	mph	°F	°F	dynes/cm
6-14-61	20-30	66	86	20-35
7-25-61	5-10	70	84	20-35

The 7-25-61 report stated that there was "animal life" in the raft. No subsequent reports were received.

New Mexico Ponds: The rafts were installed on 4-17-61. Data received were as follows:

Date	Wind Speed	Film Pressure		
		McKinney Pond	Been Pond	San Luis Pass Pond
	mph	dynes/cm	dynes/cm	dynes/cm
4-20-61	4-12	5-20	10-20	10-35
5-26-61	5-12	10-20	10-20	10-20
7-1-61	-	10-20	-	5-20

Many more readings and observations were made on these ponds than are shown, but they had not been transcribed from field books and sent to us as of 2-15-62. We were verbally advised that two major problems were encountered. During warmer weather the raft screens became clogged by bacterial growth so that distribution of the monofilm was seriously reduced. Stranding of the rafts was a problem on some ponds where the wind blew from the shallow end toward the deep water. The rafts had to be anchored in the shallow water and became stranded as the water level fell.

CONCLUSIONS:

Limited data received from cooperators showed that bacterial action seriously interfered with the operation of the rafts and that corrective measures must be developed. Stranding of the rafts as water levels declined was a problem on some ponds. Alternate methods of material application, possibly in liquid form, will be investigated.

PERSONNEL: L. E. Myers, G. W. Frasier, C. L. Jenson.

TITLE: INSTRUMENTATION FOR TURBULENT TRANSFER STUDIES

LINE PROJECT: SWC 4-gG2 CODE NO.: Ariz.-WCL-16

INTRODUCTION:

In aerodynamic studies of evaporation and transpiration one of the elements requiring accurate measurement is the moisture content of the air. For profile measurements, a precision of about 0.01 mb is desirable. Indirect measurements that lend themselves to automatic registration have not appeared satisfactory under conditions prevailing in Central Arizona (low relative humidity, high air temperature, high insolation, dust) or appeared too demanding with regard to calibration. Among methods investigated and tentatively rejected are: wet and dry bulb hygrometry, electric conductance (LiCl) methods, and infrared absorption.

It was decided to go back to a non-automatic, absolute method, generally known as a chemical hygrometer. In this method a known volume of air is passed through a moisture absorber and the gain in weight is measured. Two separate quantities must be determined: flow volume or mass, and weight. The flow volume can be accurately determined and even more precisely controlled. Weight can be very accurately determined. Thus, the method has promise of accuracy and dependability because there is no implication or reference to other methods involved. In this sense it may be called an absolute method. For many purposes another advantage is that the method gives a true time-average.

PROCEDURE:

Principle. By means of an air pump and a vacuum regulating device a constant negative pressure is maintained at one end of a fine capillary. This pressure is accurately measured. At the other end of the capillary the pressure is also determined and by measuring the pressure differential, time elapsed, and the flow characteristics of the capillary, the mass of air passed through it is calculated.

The capillary is connected to a drying bulb filled with "Drierite" (anhydrous calcium sulfate) and, by means of suitable tubing, to the point where air sampling is desired. The flow resistance of bulb and tubing being relatively low, the pressure at the intake end of the capillary is close to atmospheric.

The flow characteristics of the capillary are determined using water as the fluid. Water is allowed to flow at a precisely measured head difference and the flow rate is determined by weighing water and measuring elapsed time.

The weight increase of the absorption bulb is divided by the mass of air that went through the capillary, thus yielding directly the "mixing ratio," r. If the temperature of the air sampled is known, its relative humidity may be found by dividing r by r_s, the mixing ratio at saturation at the prevailing air temperature.

It is, of course, necessary to know the temperature of the air flowing through the capillary, in view of the effect of temperature on viscosity. Since only dry air is flowing through the capillary no other corrections are necessary.

NOMENCLATURE AND THEORY:

For convenience, not all units are in the CGS system, exceptions being flow rate (g min^{-1}) and pressure (mb). The following quantities are used:

Q = flow rate (g min^{-1})

r = radius (cm)

γ = density (g cm^{-3})

p = pressure (mb)

p_1 = pressure at entry

p_2 = pressure at exit

p_a = ambient pressure

μ = dynamic viscosity (poise)

L = length (cm)

$\mathcal{T}$ = transmissivity (g min^{-1} mb^{-1})

r = mixing ratio (nondimensional)

For the flow of water through the capillary we have, with laminar flow (Reynolds number below 2000)

$$Q = \frac{\pi r^4 \gamma}{8\mu L} (p_1 - p_2) \quad .$$

This formula is useful in determining the approximate length and bore of the capillary desired, but once the capillary is selected, the formula may be simplified to

$$Q = \mathcal{T}_w (p_1 - p_2) \qquad [1]$$

in which the subscript w refers to water and

$$\mathcal{T}_w = \frac{\pi r^4 \gamma_w}{8\mu_w L} \quad .$$

If the same capillary is used for metering air we have

$$Q = \frac{\pi r^4 \gamma_1}{8\mu L} \frac{(p_1^2 - p_2^2)}{2p_1} \qquad [2]$$

in which γ_1 refers to the density at pressure p_1 or the entry pressure.

Equation [2] may be written as

$$Q = \mathcal{T}_a \frac{(p_1^2 - p_2^2)}{2p_1} \qquad [3]$$

in which

$$\mathcal{T}_a = \frac{\pi r^4 \gamma_{1,a}}{\mu_a L} \quad . \qquad [4]$$

The above formula assumes isothermal flow and laminar flow. By a number of trials and calculations it was found that, in the case of air flow, satisfactory data would be obtained with a value for $(p_1 - p_2)$ of about 100 mb. Since the drop in pressure from the entry of the capillary to the intake point was minor (a few mb) and reproducibly constant, the following simplifications were made:

$$p_1 = p_a \, , \; \gamma_{1,a} = \gamma_{a,a} \quad .$$

To further simplify experimental procedure, $(p_1 - p_2)$ is measured directly, designated as Δp_1, giving instead of [3]

$$Q = \mathcal{T}_a \frac{p_a^2 - (p_a - \Delta p)^2}{2p_a} \quad . \qquad [5]$$

Thus the determination of Q is reduced to three measurements: of $\mathcal{T}_a$ - obtained by calibration, of p_a, and of Δp - the pressure differential across the capillary.

The value of p_a may be found from a barometer or equated to the average prevailing pressure--at this location, 970 mb. It can easily be shown that the latter procedure can introduce only minor errors.

It follows from the foregoing that

$$\mathcal{T}_a = \mathcal{T}_w \frac{\gamma_a}{\gamma_w} \frac{\mu_w}{\mu_a} \quad . \qquad [6]$$

Since τ_w is determined experimentally using equation [1], values for γ_a, γ_w, μ_w, and μ_a may be looked up in standard tables at the appropriate temperature and at standard pressure. Thus τ_a can be calculated.

The capillaries used in the final procedure had a bore of 6.2×10^{-2} cm (nominal 0.5 mm) and a length of about 30 cm. In calibrating these with water, a flow rate of 6 g min^{-1} obtained giving a Reynolds number of about 250. When used for air flow the flow rate was about 0.2 g min^{-1}, corresponding to a Reynolds number of 408. From this information it is concluded that the flow regime was laminar and aerodynamically similar so that the use of equation [6] was justified.

EXPERIMENTAL PROCEDURE:

Calibration. The apparatus for determining τ_w is shown in Figure 1. A constant head of about 100 mb is maintained at the left-hand side of the capillary as measured in the standpipe by means of a cathetometer. The capillary is mounted horizontally and the elevation of its center also measured with the cathetometer. The head is measured in cm to the nearest 10^{-3} cm, corrected for capillary rise in the glass standpipe and converted to mb from the density of water at the prevailing temperature.

Water is allowed to flow through the capillary for 50 minutes, accurately measured with a timer to the nearest 10^{-2} min and the water is weighed to the nearest 10^{-2} g, the average amount being around 320 g. The capillaries are about 30 cm long and they are adjusted until they yield approximately equal values of τ_w.

All measurements are made repeatedly in a constant temperature room maintained at 25.0 ± 0.3 C.

A set of capillaries was thus calibrated on September 8, 1961 giving the following values:

Number	τ_w in g min^{-1} mb^{-1} × 10^{-2}
6	6.749 ± .005
8	6.895 ± .006
9	7.085 ± .004
10	6.369 ± .004
12	6.468 ± .002
13	6.601 ± .004
14	6.566 ± .002

HYGROMETER CONSTRUCTION:

The principal application of the hygrometer is expected to be the measurement of the mixing ratio of the air at two levels above the surface over successive periods of time on the order of one hour. After extensive preliminary work the following general characteristics were adopted.

Transmissivity for air is determined by length and bore and is about 4.0×10^{-3} g min^{-1} mb^{-1}. The typical operating pressure differential is about 100 mb resulting in an air flow per hour of about 20 g. The amount of moisture in this amount of air would, of course, depend upon its mixing ratio. Typical values for Arizona are found from climatological data as follows:

Month	Dewpoint	Mixing Ratio	Moisture in 20 g air
January	0 C	3.8×10^{-3}	76 mg
April	2 C	4.4×10^{-3}	88 mg
July	16 C	11.6×10^{-3}	232 mg
September	15 C	10.8×10^{-3}	216 mg

It is likely that values considerably higher than indicated may be found close to the surface. To measure a quantity of water of the order of 100 mg adequately a weighing technique must be employed with an accuracy considerably better than 1.0 mg.

Principal components of the instrumentation are:

1. Vacuum-Pressure Pump (Gast Manufacturing Corporation, Model 0211).
2. Vacuum Regulator (Moore Products Company, Nullmatic 44-20).
3. Precision Manometer (Wallace & Tiernan, FA 145).
4. Analytical Balance (Mettler B5).
5. Adsorption Bulbs (Corning #AS 26).

A schematic outline of the equipment is given in Figure 2. The precision manometer can be connected to the inlet of either capillary. In principle the pressure differential should be identical but minor differences in upstream flow resistance may cause differences in pressure differential between the two capillaries. The accuracy of the manometer is 0.3 mb and its sensitivity is 0.03 mb. The accuracy of the balance is 0.05 mg.

With a setup as portrayed in Figure 2 a series of blank measurements was made in the laboratory in which the two inlets were joined to assure that the same air would enter into each half of the apparatus. In the example shown, two adsorption bulbs were carried for each capillary to verify the completeness of adsorption.

Time of run:	30.00 min
Average pressure differential:	102.7 mb
Average temperature:	31.3 C

Capillary #7

First bulb increase	121.8 mg
Second bulb increase	0.2 mg
Total increase	122.0 mg
Transmissivity for water at 25.0 C:	7.135×10^{-2} g min^{-1}mb^{-1}
Transmissivity for air at 31.3 C:	3.799×10^{-3} g min^{-1}mb^{-1}
Mass of air flow:	11.705 g
Mixing ratio:	10.422×10^{-3}

Capillary #8

First bulb increase	122.4 mg
Second bulb increase	0.5 mg
Total increase	122.9 mg
Transmissivity for water at 25.0 C:	7.180×10^{-2} g min^{-1}mb^{-1}
Transmissivity for air at 31.3 C:	3.823×10^{-3} g min^{-1}mb^{-1}
Mass of air flow:	11.778 g
Mixing ratio:	10.434×10^{-3}

The two mixing ratios agree within about 1 part per thousand. This favorable result was not always obtained. It proved essential to weigh very carefully, avoid contamination of the bulbs, have tight connections, use a fresh desiccant, carry a "blank" bulb and a standard weight for weighing. It is more realistic to expect errors up to 0.5 percent.

Subsequently, a multiple double hygrometer was constructed in which the flow at set intervals could be switched automatically through a different pair of adsorption bulbs. The arrangement provides for six pairs of bulbs and solenoids that are activated by a timer. By selecting the appropriate combination of motor and gear train, different intervals may be obtained. A general sketch is provided by Figure 3.

This apparatus was given laboratory and field tests and a number of shortcomings were corrected to result in a final design by January 1962. Results of a test in a constant temperature room are given in Table 1. The point of interest is the agreement between A and B, though the mixing ratio can also be expected to be nearly constant with time in the room.

SUMMARY AND CONCLUSIONS:

The absolute hygrometer design as described appears to work reliably and to result in acceptable accuracy. In terms of vapor pressure the accuracy turns out to be about 0.03 mb. Relative accuracy is between 1 and 0.5 percent. This is not as good as anticipated. Additional work will be done to improve the accuracy under simulated field conditions.

However, field tests and actual measurements in conjunction with the lysimeter system are feasible and will be carried out. Tests made so far indicate that the mixing ratio differential close to the surface is large enough to permit its close evaluation with the technique as advanced so far.

PERSONNEL: C. H. M. van Bavel, J. L. MacIntyre.

Table 1. Test of multiple absolute hygrometer.

Hour	Level	Weight Increase	Operative Pressure 1/	Air Flow	Mixing Ratio
1	A	0.1546 g	94.9 mb	21.02 g	7.355×10^{-3}
1	B	0.1581	95.1	21.52	7.347
2	A	0.1585	93.9	21.31	7.438
2	B	0.1610	94.1	21.82	7.378
3	A	0.1576	95.5	21.37	7.375
3	B	0.1599	95.5	21.84	7.321
4	A	0.1583	94.7	21.34	7.418
4	B	0.1601	94.7	21.81	7.341
5	A	0.1573	94.7	21.63	7.272
5	B	0.1587	94.7	22.10	7.181
6	A	0.1640	94.6	21.93	7.478
6	B	0.1653	94.6	22.41	7.376

1/ Defined as: $p_a^2 - (p_a - \Delta p)^2/2p_a$.

U.S. Water Conservation Laboratory,
Tempe, Arizona

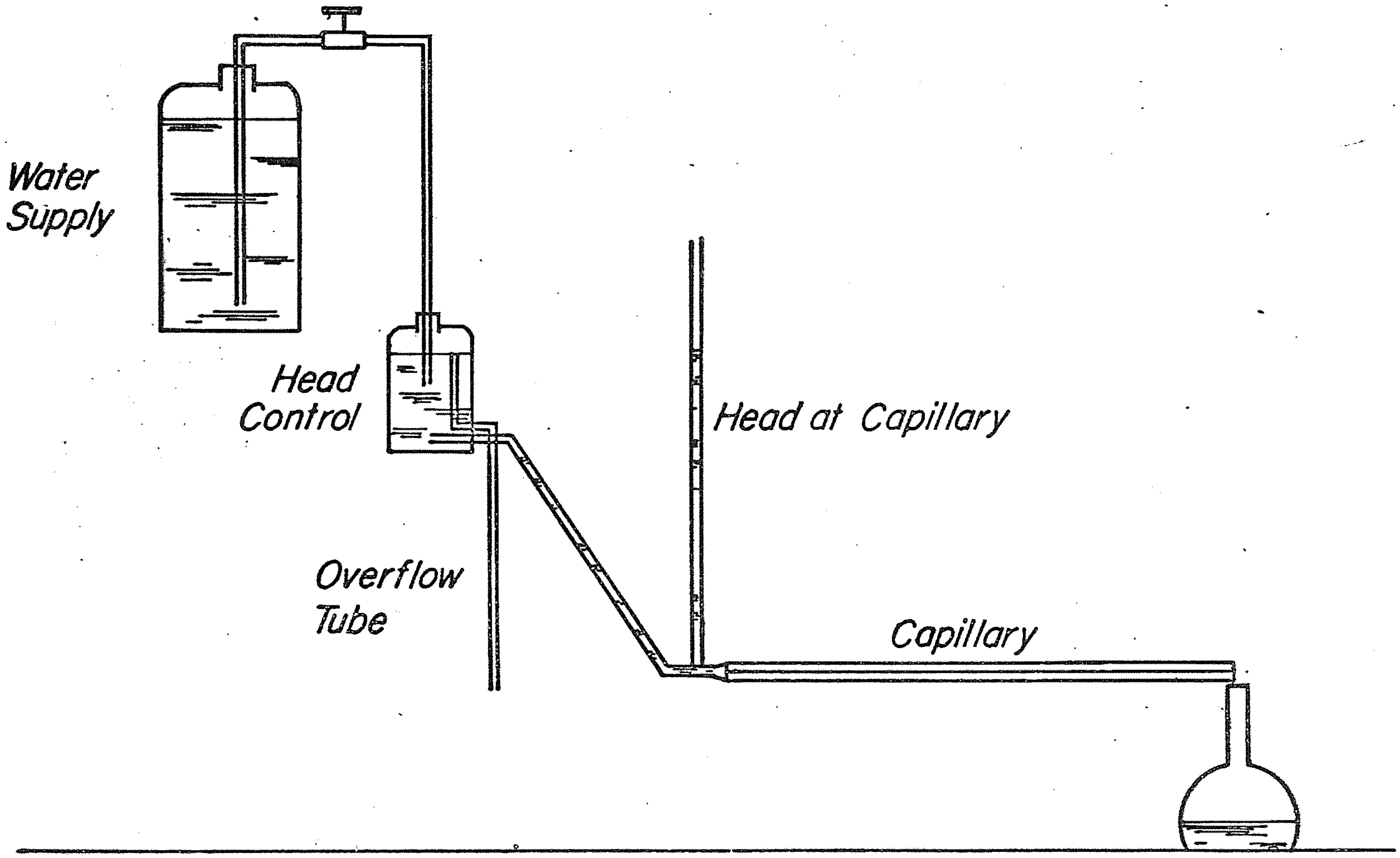


Figure 1. Apparatus for calibrating metering capillary with water.

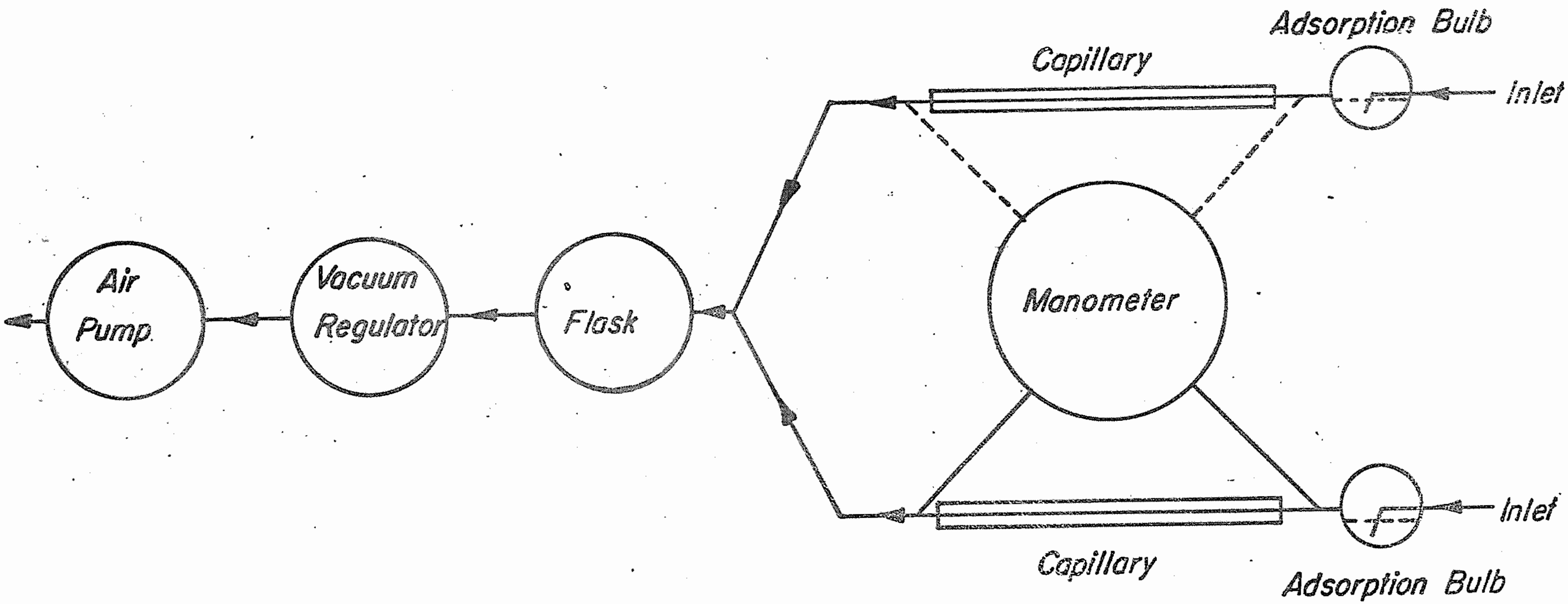


Figure 2. Schematic showing basic arrangement of dual chemical hygrometer.

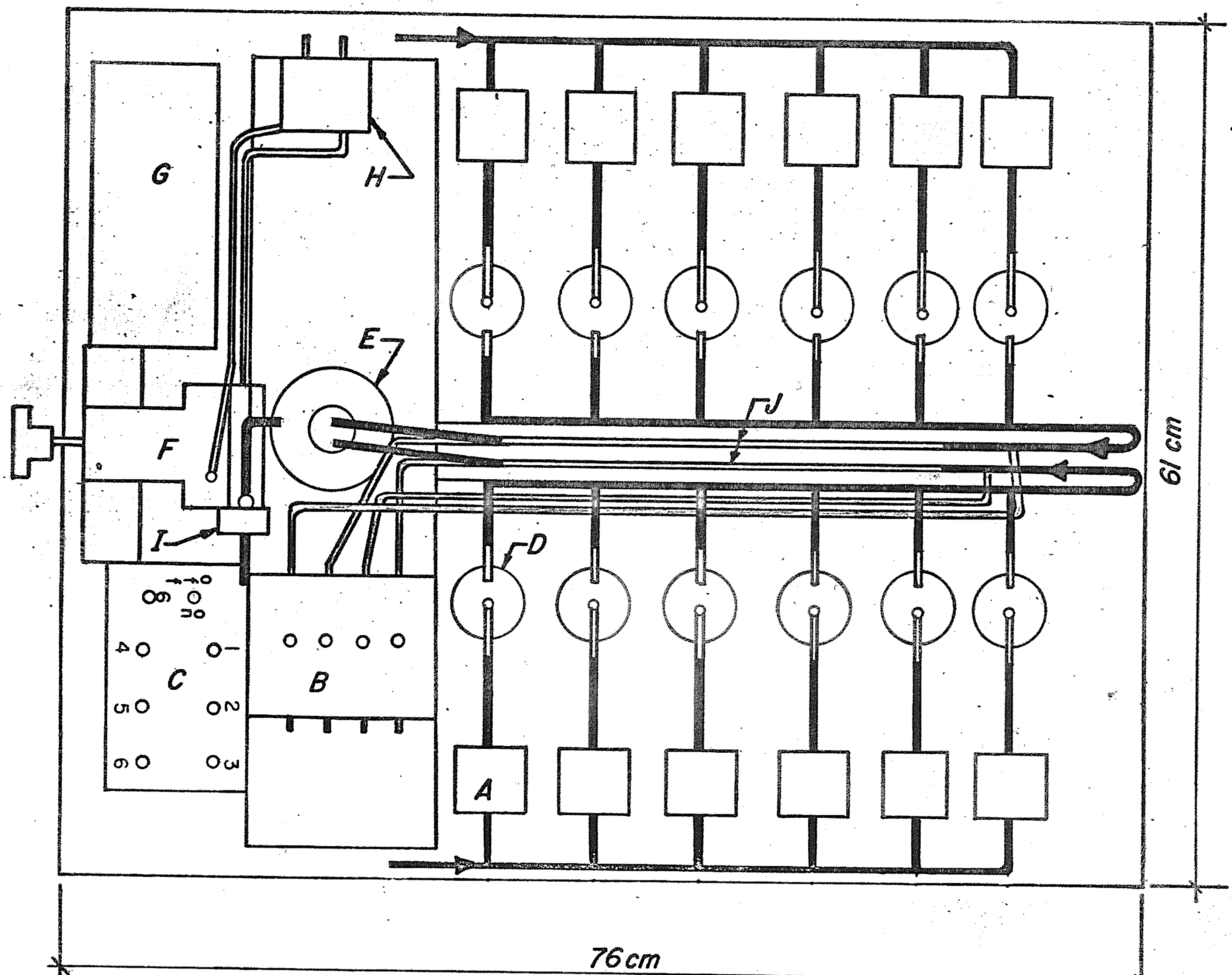

G
H
E
F
J
I
D
C
B
A
1
2
3
4
5
6
61 cm
76 cm

Figure 3. Layout of dual chemical hygrometer for automatic sampling during six successive time periods. A--solenoid valve, B--testing manifold, C--test lights for solenoids, D--absorption bulb, E--vacuum reservoir, F--vacuum regulator, G--timing switches, H--supply manifold, I--main valve, J--capillary.

TITLE: EVAPORATION FROM THE SOIL SURFACE AND SOIL MOISTURE MOVEMENT

LINE PROJECT: SWC 4-gG2 CODE NO.: Ariz.-WCL-19

PART I. MANAGEMENT AND PERFORMANCE OF THE TEMPE LYSIMETER SYSTEM

1. General

Details of the weighing mechanism and recording part of the system have been described in the 1960 Annual Report. The following is a chronological report of various operations performed on the lysimeters and field during 1961.

Date	Time	Remarks
09 Jan 61	1500	All pits completely backfilled.
10 Jan 61		Calibrate lysimeters and add new permanent counter-weights. Study on the effect of windspeed on lysimeter weight record.
13 Jan 61		Install four access tubes for neutron moisture measurements at four sites in the field.
24 Jan 61		Rainfall 0.41 mm.
26 Jan 61		Rainfall 3.35 mm.
21 Feb 61	1530	Start Little Splash #1 experiment.
27 Feb 61	1200	End Little Splash #1.
28 Feb 61		Add approximately 29 kg of tapwater to each lysimeter.
01 Mar 61	0710	Irrigate field with pump. Area of field 1.65 acres. Capacity of pump approximately 500 gal per minute. Water on field for eight hours.
02 Mar 61	0810	Irrigate field with pump and project water. Length of water application not known.

Date	Time	Remarks
28 Mar 61	1800	Rainfall 4.47 mm.
30 Mar 61	0200	Rainfall 1.71 mm.
04 Apr 61	1100	Cultivate lysimeters 4 to 6 inches deep.
05 Apr 61	0900	Start drainage of lysimeters. Apply vacuum equivalent to -100 millibars pressure potential at soil-bead interface.
07 Apr 61		Stop drainage of lysimeters.
07 Apr 61	1615	Install heat-flow plates and thermocouples in the lysimeters.
13 Apr 61	A.M.	Drag lysimeter field to break clods and to level ground.
13 Apr 61	1430	Add approximately 29 kg water to the lysimeters.
13 Apr 61	1600	Start Little Mud #1.
17 Apr 61	0800	End Little Mud #1.
17 Apr 61	1130	Cultivate lysimeters 3 to 6 inches deep.
17 Apr 61	1500	Start Little Splash #2.
24 Apr 61	0445	End Little Splash #2.
24 Apr 61	0545	Start Big Splash #1.
27 Apr 61	1130	End Big Splash #1.
27 Apr 61	1500	Add approximately 66 kg water to lysimeters.
27 Apr 61	1630	Start Big Mud #1.
05 May 61	0800	End Big Mud #1.
05 May 61	0900	Cultivate lysimeters 3 to 6 inches deep and surrounding area by hand. Start drainage of all lysimeters.
12 May 61	A.M.	Stop drainage of all lysimeters.

Date	Time	Remarks
17 May 61	1400	Install access tube in center of #2 lysimeter. Length of tube 155 cm and flush with soil surface.
24 May 61	1000	Install thermocouples in all lysimeters (25-, 50-, and 100-cm depths from soil surface).
25-26 May 61		Lysimeter field leveled by tractor.
29 May 61	0900	Approximately 70 mm water added to lysimeters.
29 May 61	A.M.	Irrigate field with pump and project water. Approximately 70 mm.
02 Jun 61	0932	Start draining all lysimeters.
05 Jun 61	0806	Stop drainage.
06 Jun 61	1000	Cultivate around lysimeters by hand.
09 Jun 61	0840	Add approximately 45 mm water to lysimeters.
09 Jun 61	A.M.	Water added to field, approximately 45 mm.
13 Jun 61	1000	Start drainage.
20 Jun 61		Thermocouple cable placed underground at 12-inch depth to each counterweight shaft from junction box in field. Cannon plug installed next to shaft.
23 Jun 61	1600	Drainage stopped.
30 Jun 61		In checking calibration of lysimeters a discrepancy was noted and #2 lysimeter could not be brought into full range. A new resistor was put in the servo-digitizer chassis and the lysimeters were recalibrated.
01 Jul 61	A.M.	The three lysimeters were again checked and recalibrated. The span on #1 and #3 lysimeters was 0 to 50 kg and on #2 it was 0 to 49 kg.

Date	Time	Remarks
02 Jul 61	2100	Rainfall 4.61 mm.
03 Jul 61	0600	Rainfall 0.44 mm.
03 Jul 61	1300	Cultivate lysimeters to 3-inch depth.
04 Jul 61	0900	Install heat flux plates in thermocouples at 5 cm depth in all lysimeters.
07 Jul 61	1100	Add approximately 70 mm water to lysimeters.
07 Jul 61	1200	Start Big Mud #2.
07 Jul 61	1600	Water on field for approximately 5 hours previous to this time. Approximately 70 mm water applied to the field.
11 Jul 61	0845	Counterweights checked to see if they touched the counterweight shaft housing. They appear to have sufficient clearance.
12 Jul 61	0800	End Big Mud #2.
12 Jul 61	1030	Start drainage.
17 Jul 61	0900 to 1600	Put lysimeter #2 on drag pen recorder for continuous readout, a second wind study.
17 Jul 61	1400	Stop drainage.
17 Jul 61	1600	Start special experiment on weight loss from lysimeters--#1 lysimeter bare, no treatment; #2 lysimeter, plastic cover and drip bottle; #3 lysimeter, plastic cover.
21 Jul 61	0830	Stop special lysimeter weight experiment.
21 Jul 61	0855	Start third wind-lift study.
21 Jul 61	1700	Stop third wind-lift study.

Date	Time	Remarks
24 Jul 61	0900	Start drainage.
28 Jul 61	2000	Rainfall, 7.69 mm.
30 Jul 61	1200	Rainfall, 5.45 mm.
04 Aug 61	1007	Stop drainage.
08 Aug 61	2000	Rainfall, 3.13 mm.
10 Aug 61		Install gated pipe irrigation system on north side of field. Pipe placed on 2- by 4-inch redwood stakes. Stakes are 1.22 feet below bench mark and 2 inches above soil surface.
11 Aug 61	0000	Rainfall, 1.37 mm.
15 Aug 61	0000 to 0900	Rainfall, 11.75 mm.
17-18 Aug 61		Field sprayed with Fenac to control puncture vine.
18 Aug 61	1900	Rainfall, 1.86 mm.
19 Aug 61	2100	Rainfall, 2.12 mm.
21 Aug 61	0100	Rainfall, 0.64 mm.
23 Aug 61	0500	Rainfall, 5.92 mm.
23 Aug 61	A.M.	New design tensiometers installed, one in each lysimeter and two in the field.
29 Aug 61	0000 to 0700	Rainfall, 16.05 mm.
11 Sep 61	0830	Start Seller's Sweep experiment.
12 Sep 61	0840	Water added to all lysimeters, approximately 30 mm.
13 Sep 61	1200	Rainfall, 10.10 mm.
15 Sep 61	0800	Stop Seller's Sweep experiment.

Date	Time	Remarks
19 Sep 61	1300	Start drainage, vacuum pump set so pressure potential at glass bead soil interface is equal to -150 mb pressure potential.
21 Sep 61	0810	Decreased pressure potential to -175 mb.
22 Sep 61	1400	Remove heat flux plates and tensiometers from all lysimeters. Cultivate all lysimeters 3 to 4 inches deep.
27 Sep 61	1011	Stop drainage.
25-26 Sep 61		Install new Butyl gaskets on all three lysimeters. Original neoprene gasket faulty.
06 Oct 61	P.M.	Install thermocouples and heat flux plates in field and lysimeters.
09 Oct 61	0000 to 0400	Rainfall, 0.66 mm.
12 Oct 61	0800	Recalibrate all lysimeters; #2 appears not to be linear. This is discussed later in the text.
13 Oct 61	0830	Tap water added to lysimeters, approximately 43 mm.
13 Oct 61	0900	Irrigate field with pump, approximately 40 mm water added.
23 Oct 61	1400	Apply 600 pounds per acre single super phosphate to field and lysimeters with hand spreader.
24 Oct 61	0900	Plow field to 6-inch depth.
25 Oct 61	0900	Disc field and drag with spike-toothed harrow.
26 Oct 61	1200	Cultivate lysimeters 2 inches deep.
26 Oct 61	1200	Throw up 40-foot wide borders in north-south direction and float the checks with a 15-foot float on the hydraulic lift of the tractor.

Date	Time	Remarks
30 Oct 61	1200	Plant Moapa variety alfalfa at a rate of 25 lb/A with hand sower.
30 Oct 61	A.M. & P.M.	Rainfall, 2.63 mm.
31 Oct 61	A.M. & P.M.	Apply water to field, approximately 85 mm with pump.
31 Oct 61	1200	Tap water added to lysimeters, approximately 30 mm.
15 Nov 61	0900	Cultivate lysimeters and around lysimeters to 2-inch depth by hand.
15 Nov 61	0900 to 1600	Spray field with BHC (benzene hexachloride) at a rate of 1/2 gal/A to control spotted alfalfa aphid.
16 Nov 61	0900	Irrigate lysimeters with tap water, approximately 30 mm.
16 Nov 61	0900	Irrigate field by borders. Put approximately 80 mm water in each border.
21 Nov 61	0100 to 0800	Rainfall, 1.51 mm.
25 Nov 61	1600 to 2100	Rainfall, 1.12 mm.
10 Dec 61	0000	Rainfall, 0.72 mm.
10 Dec 61	0400 to 0900	Rainfall, 0.57 mm.
10-11 Dec 61	1500 to 0100	Rainfall, 2.57 mm.
11 Dec 61	0500 to 0700	Rainfall, 1.61 mm.
13 Dec 61	0600	Rainfall, 0.20 mm.
14 Dec 61	0900	Rainfall, 0.10 mm.
14-15 Dec 61	1600 to 0800	Rainfall, 13.53 mm.
15-16 Dec 61	0900 to 0100	Rainfall, 5.66 mm.

Date	Time	Remarks
14 Dec 61	1300	Blow air from vacuum cleaner into counterweight shaft through the coffin and out the gasket on #2 lysimeter to help remove any moisture in the coffin of #2.
14 Dec 61	1600	Stop vacuum cleaner.
19 Dec 61	0740	Start vacuum cleaner.
22 Dec 61	1000	Stop vacuum cleaner.

2. Lysimeter Installation

In 1960 when the pits for the footings were dug the soil was removed in 30 cm layers and placed in individual piles. Each pile of soil was then passed through a 1.5 cm screen, the result being five piles of screened soil for the first five layers and one unscreened pile for the 5- to 7-foot depth. The inner bins of the lysimeters were then filled with soil from the five screened piles.

The drainage system, described in the 1960 Annual Report, was placed on the bottom of the inner bin, covered with sand and glass beads, and filled with soil. Layers of air dry soil, approximately 64 kg per layer, from the 120- to 150-cm depth were placed on the glass beads and compacted to a bulk density of 1.4 g cm^{-3}. The compaction was accomplished by walking on the soil until it reached the correct thickness. Thus about 5-cm layers of soil were compacted, one on top of another, for each 30-cm depth increment.

When the bins were filled to within 5 cm of the top, water was added and the soil was allowed to become saturated. Water was then removed through the drainage system until the pressure potential at the bottom was maintained at -100 mb. No settling of the soil was noticed. The lysimeters were then placed on the footings in late December 1960 and soil backfilled. The backfilling procedure was similar to the filling of the inner bins, i.e., placing 5-cm layers of soil around the lysimeters and compacting it by foot. However, after each 30-cm layer had been put back, 7 to 10 cm of water was applied to the soil and by the next day another 30 cm layer could be compacted. The back-filling took approximately 2 weeks.

After the area around the lysimeters was smoothed over and leveled, a series of calibration tests were conducted, as reported in the 1960 Annual Report.

3. <u>Lysimeter Moisture Regime</u>

In order for a lysimeter installation to be a truly representative sample of field conditions one criterion that must be met is that the water regime inside the lysimeter is compatible with the moisture regime outside the lysimeter. That is, the moisture content distribution inside and outside and the pressure potential relationship inside and outside should be the same.

First, consider the moisture content distribution. Neutron access tubes were installed outside of the lysimeters at a distance midway between the lysimeters and also one in the center of #2 lysimeter. Weekly measurements of moisture content inside and outside of the lysimeters are made and compared. During the various periods of wetting and drying of the lysimeters moisture content measurements were made and, as of the 21st of September, the average moisture content distribution in #2 lysimeter ran from 5 to 7 percent higher than the moisture content distribution at comparable depths outside the lysimeter field. Since that time however, repeated drainage cycles have been carried on and at the end of November 1961 no moisture content profile differences could be detected between #2 lysimeter and the outside field. Therefore, we can safely assume that the moisture content distribution within and without the lysimeter are similar.

Next, we consider the pressure potential distribution within and without the lysimeter. Pressure potential measurements are made with tensiometers at a depth of 150 cm inside and outside the lysimeters. The average pressure potential outside of the lysimeter runs slightly higher than the inside of the lysimeter at the 150-cm depth. The pressure potential outside may run -105 to -110 mb while the pressure potential inside the lysimeter may run -95 to -100 mb; a small difference.

Therefore, we conclude that the moisture regime inside and outside of the lysimeters is very similar. Additional time will serve to enhance these conditions.

4. <u>Drainage System Performance</u>

The drainage system which has been described in the 1960 Annual Report has performed satisfactorily for us this entire year. The object of this drainage system is to maintain the pressure potential at the bottom of the lysimeter comparable to what it is at an equal depth outside of the lysimeter. This is accomplished by noting the values of pressure potential on a tensiometer in the field and in the lysimeter. When the difference between the two tensiometers is approximately 20 mb, that is, the pressure potential out of the lysimeter, a vacuum pump and flask is connected to the lysimeter and a pressure potential equal to that of outside conditions is maintained at the bottom of the lysimeter through the drainage system. The time for drainage varies with the amount of water that must be removed but an average of 3 to 5 days is required in the drainage cycle.

The rate of drainage has not decreased since the drainage system was first installed in December of 1960. This indicates that the porous stainless steel plates have not clogged up and the glass bead filter is still in good shape.

5. Irrigation System for Lysimeter Field

The lysimeter field has been divided in approximately 7 equal-width borders, the borders running north and south. There are two buffer borders on the east side and two on the west side and one lysimeter in each of the three center borders. In order to irrigate each border separately, 300 feet of gated pipe was installed at the north end of the field. This gated pipe was then connected to a low-lift pump which pumped water directly from a ditch. The capacity of the pump is approximately 500 to 550 gallons per minute. The gates are set on 40-inch centers, so, when irrigating one check, 12 gates are usually open. The area of each gate is 2 square inches. Between the pump and the gated pipe is an 8-inch Sparling meter. This meter has been calibrated against a standard 3-inch elbow and the appropriate calibration curve obtained. The accuracy of this calibration curve is within 1 percent of the value obtained with a standard V-notch weir.

The meter reads directly in gallons and with appropriate dimensional analysis the gallons can be converted directly to millimeters of water for each border. We therefore have an accurate measure of the amount of water that is put on each border during each irrigation cycle. It takes approximately 45 minutes to apply 70-80 mm water depth on one border.

6. Recalibration of Lysimeter System

The following procedure was used to recalibrate the lysimeters at various periods of time. First the end points or the span was fixed by adding 50 kg to the lysimeter and properly counterbalancing the counterweight shaft until we had a readout of 0000. The 50 kg was then removed from the lysimeter and a readout of 5000 was obtained. Intermediate weights were then added and the digital readout was compared to the amount of weight added. This calibration procedure fixed the end points and tested the linearity over the range that we were to use the lysimeters.

The calibration procedure had to take place during periods of low wind speed so that the lysimeters would settle down to a constant output rapidly. Three sensitivity checks were also made during the year. This was accomplished by putting small known weights, 10, 20, 50, and 100 grams, on the lysimeter and noting the digital readout.

As mentioned in the chronological report, during October a calibration procedure was run and #2 lysimeter seemed to depart somewhat from linearity over the entire range. The maximum deviation from linearity was 700 grams. That is, when 37.50 kg was placed on the lysimeter the actual digital readout was 38.20. The deviations were negligible near the end points however.

This departure from linearity on #2 lysimeter was thought to be associated with a short circuit in the load cell due to moisture condensing on the terminals in the coffin of the lysimeter at the load cell. Actual condensation on the shaft housing could be noted when the counterweight shaft was opened. To rectify this condition, desiccant bags were placed in the counterweight shaft above the removable counterweights and the desiccant checked periodically and changed as it picked up moisture. In December 1961, air from a vacuum cleaner was blown into the counterweight shaft, down through the coffin, and up the sides between the inner bin and outer bin and exited through a slit in the gasket to speed-up this drying process. Periodically, in December the resistance of the load cells was checked with an ohmmeter when the power to the load cells was disconnected. This resistance should be infinite. However, initially on #2 lysimeter the resistance was 1.4 million ohms. Increased drying should rectify this condition rapidly.

7. General Lysimeter Performance

Since the lysimeters were installed in December 1960, they have been run almost continuously for a period of a year. During that time minor difficulties with the machinery were encountered but rectified very quickly. The lysimeters have performed quite satisfactorily and evaporation data by hours for each day has been collected during 1961.

PART II. SOIL TEMPERATURE AND HEAT FLUX IN LYSIMETERS

INTRODUCTION:

The lysimeters are taken to be representative samples of the surrounding area. Measurements of evaporation, net radiation and soil heat flux and temperature at, over, or in the lysimeters should closely approximate similar quantities in the surrounding field. These considerations apply in particular when a surface energy balance is made up for a specified period of time and when its nature is compared to aerodynamic studies made over the field as a whole.

The lysimeters are, to an extent, isolated from the surrounding profile. There is the double steel wall and the space below the soil block which is occupied by air, concrete, and the weighing mechanism. The extent of this space has been minimized, but there may still be appreciable effects on soil temperature and heat flow. In order to investigate this particular aspect a series of measurements was made in October 1961.

PROCEDURE:

Soil thermojunctions were made from 30 gauge copper-constantan wire. The individual conductors were nylon insulated and the two jointly covered with an additional coating of nylon resulting in an overall cross section of 1 by 1/2 mm (Thermo Electric Company, Saddlebrook, New Jersey, Type NN). Materials previously used to insulate the thermocouple junction did not prove satisfactory.

The thermocouples were soft soldered and the junction covered with molten nylon. The junction was then cemented in a small hollow brass point, 2.35 mm O.D. To install the thermojunction, a brass rod was used to insert the hollow point and junction to the proper depth. The rod was then removed leaving the junction and wire behind in place. Since the soil is practically free of gravel or rocks this method works quite well.

Junctions were installed in the three lysimeters and in two adjacent locations at depths of 5, 25, 50, and 100 cm. The output from the 20 junctions was measured by the Datex data logger on the compensated range using a 21st channel for an ice bath junction to serve as reference.

Also, at the five locations, heat flux plates were installed at a depth of 5 cm. These are basically copper-constantan thermopiles embedded in polyvinylchloride (National Instrument Laboratories, Washington, D. C., Model HF-2) with a thickness of 3.3 mm and a diameter of 50 mm. Output at a resistance of 100 Ω is about 40 mv per ly min^{-1}. The heat flow plates were also programmed into the Datex data logger.

Measurements were made every hour on the hour and the data punched in paper tape. The tape was printed out with the automatic typewriter and summarized by hand. A condensed schedule of events is as follows:

October 6	Installation of Sensors
October 6-12	Checkout of Equipment and Procedures
October 13	Irrigation of Lysimeters and Field
October 14-15	Collection of Data
October 16-18	Drying of Surface
October 19	Collection of Data

RESULTS AND DISCUSSION:

Data are available for each depth, location, and time of day for each of the three days of observation. These are not given here. Instead, a condensed summary is shown in Table 1 giving the 24-hour average of the temperature at four depths, averaged for the three lysimeters and the two outside locations on each day.

It may be seen that on the two days immediately after irrigation the lysimeter soil as a whole is slightly cooler though the difference is less than one degree C and not consistent. On the 19th of October the lysimeter is somewhat cooler at 100 cm but warmer at all other depths. Again the difference is one degree C or less.

The consistency of the difference at the respective depths is shown in Figure 1, which refers to the soil temperatures on the 19th of October. Differences between the lysimeter and the outside appear well above experimental error and should be regarded as read, however small in absolute magnitude.

On all three days the soil heat flow at 5 cm tended to be smaller in the lysimeter than in the surrounding soil whether the values were positive or negative. However, as the surface dried out and drainage proceeded the differences became quite small, no greater at any time than 0.03 ly min^{-1} and typically around 0.01 min^{-1}.

The condition on October 19th is illustrated in Figure 2. The soil conditions in the lysimeters are not entirely identical to those around them. As a result of excavation, sieving, and repacking, one would expect differences in pore size distribution and moisture content distribution. Actual measurements indicate moisture content in the lysimeters to run a few percent by volume higher than outside at comparable depths. Accordingly, the temperature regime may not be expected to be the same either. However, the measurements reported here show that the differences in temperature are quite small and that the effect on soil heat flow is of the same order of magnitude as the uncertainty of hourly amounts of weight change.

Present data show that the lysimeter in this aspect is a representative sample. It will be necessary, however, to repeat the program of observations under different ambient conditions, probably during the late spring.

Table 1. Summary of soil temperatures.

Depth (cm)	Average Temperature					
	October 14		October 15		October 19	
	Outside Locations	Lys.	Outside Locations	Lys.	Outside Locations	Lys.
5	19.54	18.63	18.70	18.25	17.98	19.04
25	23.40	24.52	21.54	21.08	19.56	20.76
50	24.54	23.52	22.80	22.88	20.64	21.66
100	25.16	24.68	25.10	24.57	24.14	23.40

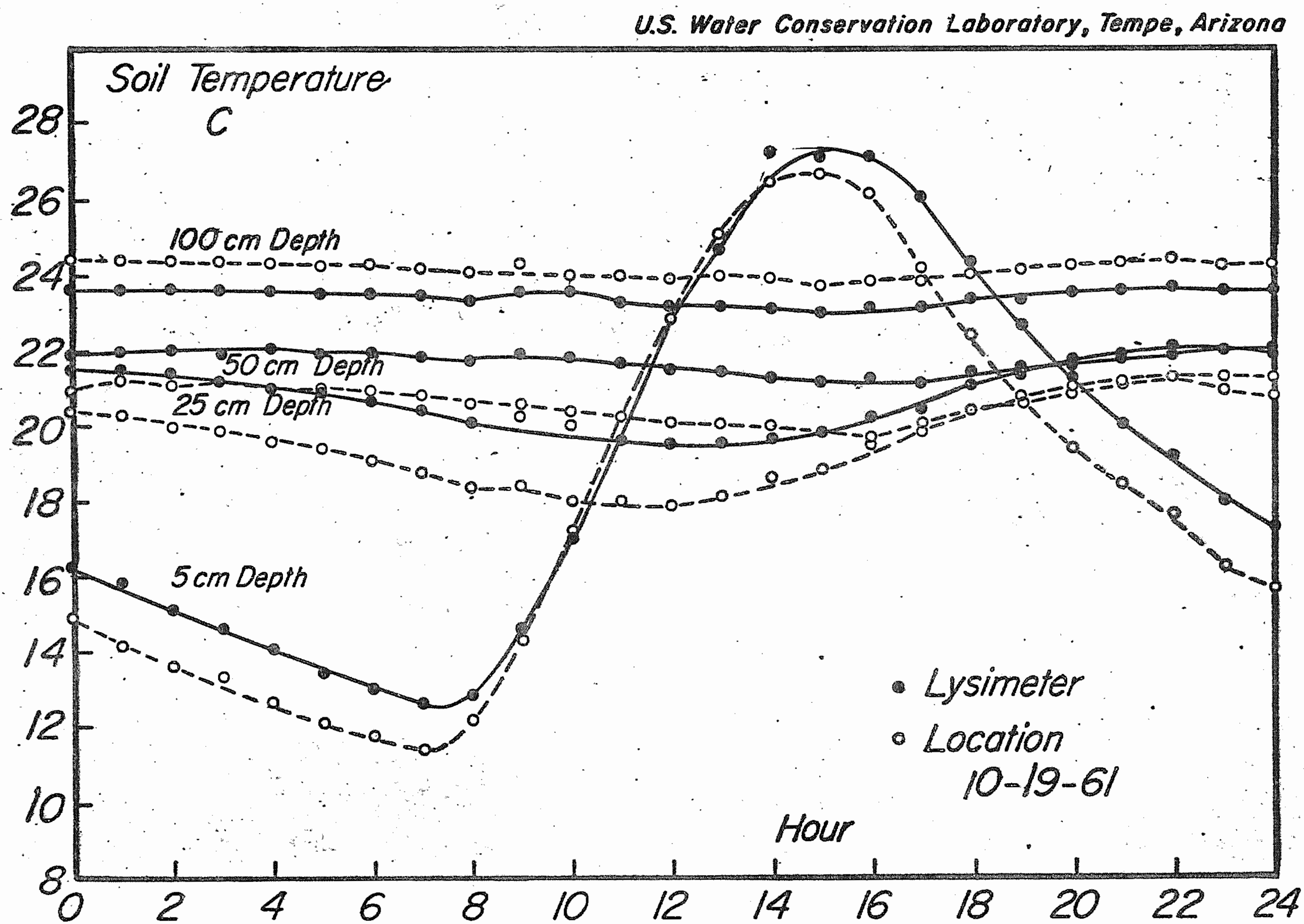


Figure 1. Soil temperatures inside and outside the lysimeters on October 19, 1962.

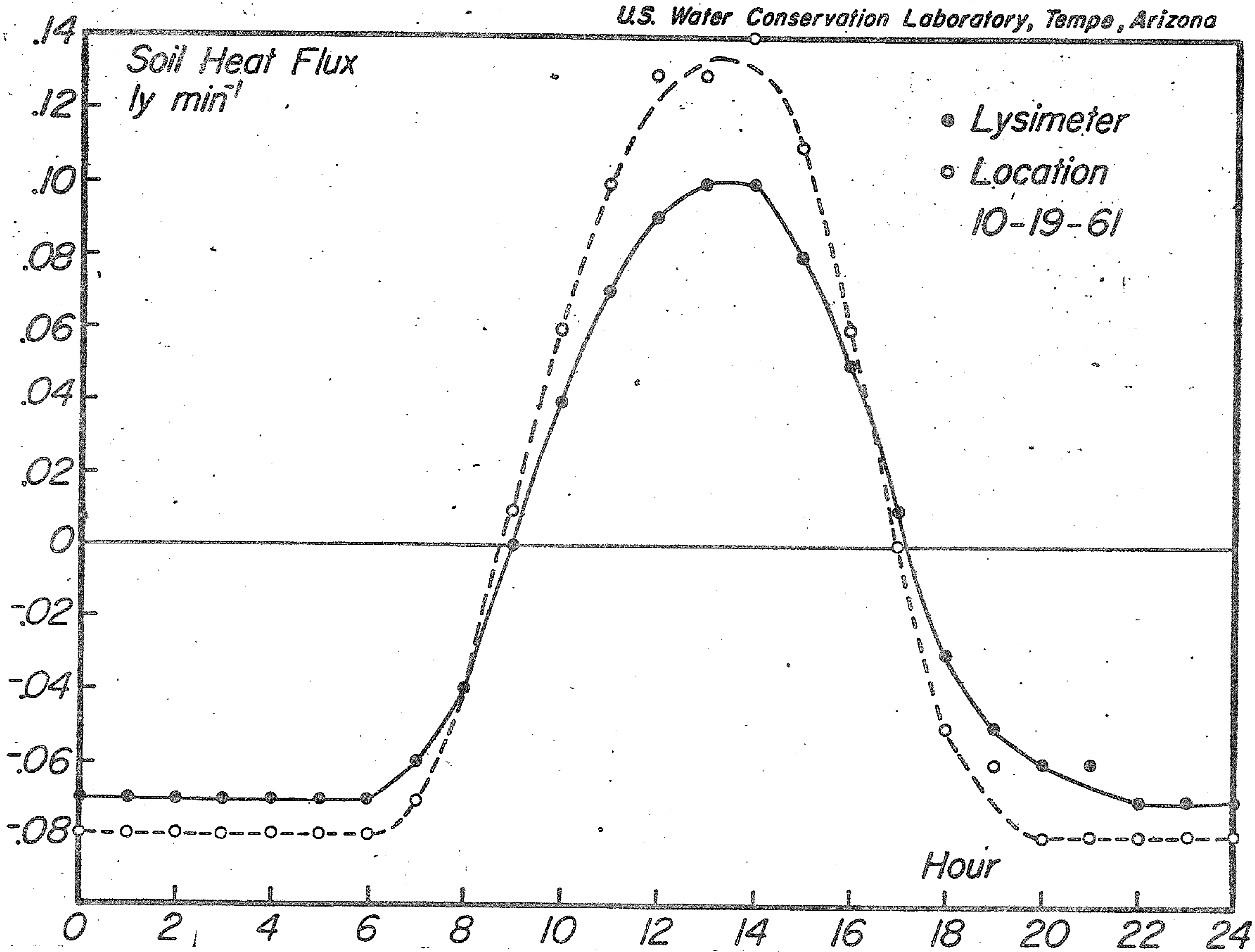


Figure 2. Soil heat flux at 5 cm depth inside and outside the lysimeters on October 19, 1962.

PART III. OBSERVATIONS AND ANALYSIS OF EVAPORATION RATES FROM BARE SOIL

INTRODUCTION:

The rate of evaporation from the soil surface is a matter of considerable practical and theoretical interest and has been investigated by a number of scientists. These investigations have ranged from extensive theoretical studies consisting mostly in application of moisture flow theory to the case in point and also of experimental studies both in the laboratory with artificial soil columns, and actual observations of the rate of drying of natural soils when exposed to the atmosphere after initial wetting.

The present studies are primarily aimed toward the procurement of representative data on the true rate of loss of water from wet soil by surface evaporation. In many previous studies this quantity was approximated from repeated samplings of the moisture content of layers of soil close to the surface or by studying the loss of weight from relatively shallow containers filled with soil and exposed in a representative manner. Such observations are not altogether conclusive. In measuring soil moisture content changes it is difficult to separate downward from upward flow. Also, the precision of direct measurement of soil moisture content is not sufficient to study short-time evaporation rates as exemplified by the amount of moisture returned to the atmosphere during one or several hours, particularly when, as a result of surface drying, evaporation rates are considerably less than what they are initially after wetting. Studies carried out by directly weighing relatively short columns of soil are capable of giving information on short-time evaporation rates but the conditions under which evaporation takes place are not, as a rule, representative of those in an undisturbed profile.

Theoretical investigations, such as those carried out in Australia by CSIRO and by the U. S. Salinity Laboratory, tend to show that moisture conditions, in terms of conductivity and distribution of potential, at considerable depth have a profound influence upon the rate of evaporation from the surface. Thus, the elimination by a horizontal barrier of moisture flow from all but the most shallow layers of soil from the process of supply of moisture to the surface where it is presumably evaporated, is likely to result in values for the evaporation rate that are not representative of those that take place from a soil profile that is not similarly disturbed.

It may be stated that, at the present time, accurate data are lacking on evaporation from bare soil under natural conditions and sufficiently long columns and, also, that no data are available on short-time rates, such as hourly or half-hourly rates, so that the daily march of evaporation rate can be adequately studied. Most studies deal with surface evaporation either as a purely meteorological phenomenon or as a phenomenon determined by the physics of soil moisture movement. Even the most superficial study would indicate that neither of these two views is entirely applicable. The daily variation of evaporation rates from bare soil is definitely the result of meteorological factors whereas the absolute magnitude of the evaporation rate, during the daytime at least, is also very definitely determined by the flow conditions in the entire profile. The purpose of the current investigations is primarily to collect reproducible, reliable, and typical data which may permit an analysis of the phenomenon in terms of the two processes that are involved and/or to enable the design of future experiments or plans of observations which will facilitate such an analysis.

PROCEDURES:

A. Drying Cycles. During the calendar year 1961 only a limited amount of precipitation was measured at the Laboratory location, approximately 20 mm. The opportunity for observing the drying of surface soil by means of the lysimeter system consisted in a number of surface irrigations at various times of the year followed by drying periods of varying lengths. These are referred to as drying cycles and they are briefly enumerated and described in Table 1.

During each one of the drying cycles any of several events occurred which may have had some bearing on the results obtained. These are indicated briefly in the following.

During Cycle 1 the weather was generally near-perfect. However, during the period May 5 through May 12, approximately 20 mm of excess water was removed from the lysimeters by drainage. The manner in which this was done did not permit the exact calculation of the daily total of evaporation and, also, did not allow the computation of hourly amounts for the period indicated.

During Cycle 3 generally perfect weather prevailed but drainage of the lysimeter took place during the period of June 13 through June 23. However, in this case by weighing the amount of water drained every day it was possible to compute the daily amount of evaporation. Hourly amounts are not available for the drainage period.

During Cycle 4 drainage was also effected in a similar way, starting on July 12 and continuing through August 4. In addition, some severe weather was encountered in the form of a dust storm and windstorm on July 14 and 16, and rainfall in the amount of about 8 mm on July 28 and July 30. As a result of these conditions and some experimental difficulty during this period the data of Cycle 4 are probably not representative, nor entirely reliable.

Cycles 5 and 6 are characterized by generally fair weather, absence of rainfall, and any interfering factors. A near-perfect record of daily and hourly amounts was obtained during these two cycles.

In Cycle 7, partly cloudy weather was experienced during Days 1 through 8 and small amounts of rainfall between 1 and 1 1/2 mm were recorded. The weather was generally fair with sharply declining air temperatures, however, for the remaining 14 days of the cycle. A perfect record of hourly and daily values was obtained on all three lysimeters.

The actual daily amount of evaporation in the form of the average amount from midnight to midnight for the three lysimeters is given in Table 2. These data have been used in subsequent analysis. Hourly data are on file but are not supplied with this report.

B. <u>Method of Analysis</u>. If the evaporation process may be considered as determined by liquid flow in one direction it is a reasonable supposition that the accumulated amount of evaporation should be directly proportional to the square root of time. This is the same as saying that the rate of evaporation should be proportional to the inverse square root of time. In other words, the evaporation process is then considered to be a special case of desorption of an infinite or rather long one-dimensional column and a case of non-linear diffusion.

To examine this proposition, the accumulated evaporation, starting with the first day after wetting, was plotted for the six cycles against the square root of time in Figure 1. It may be seen from this figure that in first approximation the relationship between accumulated evaporation and the square root of time is linear for the entire drying cycle or for a part of it. For Cycle 1 two distinct portions are indicated. The first one, A, pertains to drying of the lysimeter prior to drainage and the second portion, B, designates the drying after drainage had been carried out for approximately 6 days. In Cycles 3 and 5 only one phase of the relationship is distinguished. In Cycles 4, 6, and 7 a non-linear portion labeled A is indicated during the first few days of the drying cycle and a linear portion, B, is recognized during the remainder of the period. The segment A in these three cases is associated with drying rates which are thought to be entirely controlled by the prevailing meteorological conditions. Typically, during this period the daily rate of evaporation is nearly the same or perhaps even higher, on Days 2, 3, and 4 than on Day 1. On succeeding days the daily amount of evaporation continually declines and a linear relationship may be used as a model.

To further examine the proposition in Figure 2 the daily rate of evaporation is plotted versus the inverse square root of time. In this case, only those data are used that are associated with the linear part of the relationship in Figure 1. That is, Day 1 is the first point that appeared to lie on the linear segment B. This distinction is, of course, not applicable to Cycles 1, 3, and 5. Although some scatter is evident it may be seen in Figure 2 that a reasonably closely defined linear relationship exists between the two quantities plotted in all cycles. However, another phenomenon becomes apparent through this method of plotting. That is, after a certain minimum daily rate of evaporation has been reached there is a tendency for the relationship to flatten out into a horizontal curve indicating that with the progress of time, evaporation is no further appreciably reduced. This may be seen in Cycles 1, 3, and 6. It is believed that this portion of the relationship represents conditions under which the evaporation rate is primarily a transfer of moisture in the form of water vapor, no longer controlled by liquid flow.

The foregoing data apply to daily amounts of evaporation. In a sense this is a fictitious quantity because at no time, or very short times only, during the day will the evaporation rate actually equal the daily rate. We may indeed criticize the foregoing method of analysis in saying that we are not relating two realistic physical quantities. The manner in which the actual evaporation progresses with time must be obtained by studying short-time records. For this purpose evaporation was calculated for individual hours of each day. This was done by plotting the individual weight curves of each lysimeter and by smoothing these curves and finding the difference in weight from one hour to the next from the smoothed curve. In most cases the weight curve is very well defined and smoothing is not necessary. However, when wind disturbs the weight record somewhat, particularly during periods of low evaporation, random variability of the record can be appreciably reduced by the smoothing process. The data thus obtained are presented in Figures 3, 4, 5, 6, and 7 for Cycles 1, 3, 5, 6, and 7 respectively.

Cycle 1, shown in Figure 3, is actually identical to the "Big Mud" experiment discussed elsewhere in this report. It should be noted that the record is interrupted, as far as hourly values are concerned, during the period May 5 through May 12. In the period before drainage, the evaporation rate was substantially different from zero during the night period averaging about 0.05 mm per hour. After the drainage period the evaporation rate was essentially zero during the night hours.

Cycle 3 is portrayed in Figure 4. Here again the period June 13 through June 23 is not represented because hourly values were not available. It may be noted again that not only the daily maximum but also the nightly minimum is subject to a continuous reduction from day to day.

Cycle 4 is not represented because too few data were available.

Cycle 5 is probably the best one during the calendar year since conditions were remarkably uniform throughout the period of drying. Similar observations can be made for this cycle as for previous ones, in that there is a constant diminution of both the daily maximum and minimum evaporation.

Cycle 6 as shown in Figure 6, is rather different from the previous one inasmuch as a period of constant behavior over the five successive days precedes the period of drying during which the daily total continued to diminish. This corresponds to the section A that was noted in Figure 1 for Cycle 6. From Figure 6 it is evident that the separation between segments A and B of the curve in Figure 1 is somewhat arbitrary.

Finally, Cycle 7 shows a somewhat indifferent behavior during a period of low evaporative demand which is interrupted by some cloudy days and occasional light rains. Nevertheless, features similar to that in previous cycles have been preserved and the daily totals show a definite regularity as evidenced by Figures 1 and 2.

DISCUSSION:

In the course of the 1961 work only the first five days of Cycle 1 (Big Mud #1) were examined in great detail as far as the controlling meteorological conditions were concerned. The other data are mere observations which will lend themselves only to cursory examination and discussion. In the near future more detailed studies will be made of pertinent variables in the soil and in the atmosphere immediately above it.

From the results as shown in Figures 1 and 2 it is apparent that a recurrent regularity can be observed in the change of the daily rate of evaporation with time. At least a sizeable portion of the data does seem to follow the square root of time law as a consideration of moisture flow theory would suggest. However, in several instances (Cycle 4, 6, and 7) it is evident that this regularity is preceded by a period of several days in which the daily evaporation rate is controlled by meteorological conditions or that some in-between situation prevails. In this regard it is of importance to note that the transition between the two phases of evaporation is not clearly or directly associated with the state of dryness of the superficial layer. For example, in Cycle 1 the radiation conditions were identical on Days 2, 3, 4, and 5 (on Day 1 radiation was less due to cloudiness). We may observe during these four days a steady diminution of the daily evaporation rate. This is evident in Figure 2 where Day 6 is marked. Yet the surface condition of the soil did not visibly change until Day 5 and even at that point a further visible drying occurred. This is an observation which is supported by data on net radiation although this is not a direct measurement of the surface dryness. It is obvious that in order to settle this point with more certainty, detailed measurements will have to be made of the moisture content of superficial layers of soil. However, similar observations were made repeatedly during the other cycles, that is, the effect or predominance of flow of moisture in the soil as a factor in determining the daily evaporation rate occurs before one may state that the surface is entirely dried out to the extent that it would be in vapor pressure equilibrium with the atmosphere above it.

It is equally clear from the data that at the end of a drying cycle the square root relationship no longer applies. This is rather effectively masked in the accumulative curves of Figure 1 but in some of the relationships portrayed in Figure 2 (not all of the final days of a cycle were plotted here because of congestion of data) the daily rate of evaporation does not continue to decrease and finally become zero. Rather, it assumes a near-constant value after a number of days. This is also well demonstrated by the data in Table 2 and Figures 3 through 7. It is hypothesized here without further proof that during this part of the cycle, which will continue for a rather indefinite period of time, loss of water from the soil is determined by a vapor transfer process. At the same time the daily rates of evaporation associated with these conditions are by no means negligible, being of the order of about 1 mm per day. It is pertinent here to observe that at the beginning of the year 1961 the soil was permitted to dry out for a period as long as 2 1/2 months and at the end of this period the evaporation rate was still on the order of 1 mm per day.

It is evident from considering the daily totals by themselves that evaporation from dry soil is not a simple process or one that can be clearly dissected in a number of different phases. The complexity of evaporation becomes even more apparent when the actual rate of evaporation, as given by the hourly values, is considered. Judging from available data, during periods less than 1 hour the evaporation rate does not deviate materially from the hourly values, other than as caused by random errors. The record of all cycles as given in Figures 3 through 7 shows that at all times evaporation is a process determined in part by meteorological conditions. This is obvious during the first few days of a drying cycle but if the process in a later stage was determined solely by moisture flow upward, the daily variation might be damped out or disappear altogether. On the contrary, the record shows that a very regular daily pattern prevails indefinitely with a minimum at times near zero during the hours of darkness and with a rather symetrically distributed daily variation showing a maximum between 1200 and 1400. Thus the evaporation from partially dried soil will have to be analyzed as a phenomenon that involves both the monotonically declining ability of the soil to transmit water as its moisture content decreases and the periodically varying demand function. In later stages it will probably be necessary to take into account the periodically varying gradient of vapor pressure in the soil. Furthermore, the record as given in Table 2 implies that the evaporation rates as finally obtained at the end of a cycle are somewhat higher in the summertime than they are in the fall and winter which is again evidence that there may be more involved than merely transfer of moisture as determined by soil properties. It is possible that the variation in moisture flux at the surface as it is found with the lysimeter may be damped out at a relatively shallow depth below the surface. This will have to be examined in the future.

A further observation of interest is that in no single case in the record as given here was there any evidence of accretion of moisture from the atmosphere during the nighttime hours. This statement is also true for all of the records that were obtained during the year 1961. It may be concluded that under the prevailing conditions over a bare surface, dewfall as a form of precipitation did not occur in measurable quantity. Whether this same statement would also apply to a vegetated surface remains to be seen as a result of future investigations. Condensed moisture, also often referred to as dew, may be observed frequently in the Phoenix area. From a hydrologic point of view it is of interest to know whether this dew constitutes dewfall or whether it is merely recondensation of moisture that evaporated in the soil and migrated toward the surface and up to the vegetative canopy where it was recondensed.

SUMMARY AND CONCLUSIONS:

Seven distinct drying cycles were observed during the year 1961 consisting in gradual drying of the soil column after an initial wetting by irrigation. The evaporation rate in all seven was studied closely in terms of hourly rates for a period of as many as 27 days. Of the available records, 6 cycles yielded reliable data in terms of daily amounts and 5 cycles could be usefully analyzed in terms of hourly evaporation rates.

Analysis of daily evaporation amounts indicates that at least during part of the drying cycle the accumulated evaporation is directly proportional to the square root of time implying that flow of moisture in liquid form is an important aspect of the process. At the beginning of a cycle in some cases the evaporation is probably entirely determined by meteorological conditions. At the end of a drying cycle indications are that flow of water in vapor form is involved. The quantitative separation of the three mechanisms is not possible on the basis of the data gathered during 1961 and further confirmation of the hypothesis made above will rest upon future experiments.

Study of the hourly amount of evaporation indicates that throughout the conditions typifying an individual drying cycle, the evaporation from bare soil is a daily varying phenomenon with rates at near zero during the period of darkness and a distinct maximum at, or slightly after, the noon hour, indicating that under all conditions the meteorological elements play an important role. To what extent the daily variation in surface moisture flux is associated with similar variation of moisture flux in deeper soil layers and to what extent this is reflected in daily variation of moisture potential and vapor pressure is again a subject for future investigations. The records show that even after long periods of drying the evaporation rates are still appreciable during the middle of the day and also over the day as a whole. This observation should have some considerable significance in the field of watershed hydrology or in dry-land moisture conservation. To what extent this phenomenon is of any consequence in irrigated agriculture is somewhat questionable.

The investigations reported can be regarded as preliminary only. Nevertheless, it is clear that evaporation from dry soil is a complicated process that may not be justifiably simplified to a matter of one operative process only. Future investigations will attempt to simultaneously obtain data on various processes and quantities involved.

Table 1. Drying cycles on lysimeters.

Irrigation			
Cycle No.	Date	Amount	Duration
1	27 April	65 mm	28 days
3	9 June	44 mm	27 days
4	7 July	70 mm	32 days
5	13 October	43 mm	17 days
6	31 October	30 mm	15 days
7	16 November	30 mm	22 days

Table 2. Daily amounts of surface evaporation from lysimeters in mm during 7 cycles of wetting and drying.

	Cycle					
	1	3	4	5	6	7
Day 1	5.66	8.74	8.79	8.13	3.03	2.60
2	6.80	6.32	8.74	4.81	2.79	1.78
3	5.63	3.79	5.63	2.97	2.62	2.14
4	4.31	1.82	3.02	2.54	2.80	2.46
5	3.55	2.36	2.24	1.83	3.47	2.31
6	3.13	2.27	1.15	1.43	1.93	1.79
7	2.39	1.97	1.82	1.45	1.24	1.81
8		1.53	1.74	1.20	0.87	1.43
9		1.12	1.86	0.86	0.74	1.26
10		1.38		0.72	0.88	1.27
11	9.00 ~~22.37~~	1.33		0.67	0.74	0.99
12		1.37		0.60	1.03	1.06
13		1.30	No Data	0.56	0.77	0.58
14		1.69		0.52	0.65	1.00
15		1.28		0.63	0.96	0.86
16	0.63	1.23		0.28		1.04
17	0.66	1.25		0.25		0.59
18	0.74	1.17	0.72			0.62
19	0.76	1.08	1.19			0.61
20	1.11	1.03	1.06			0.50
21	0.79	0.84	1.57			0.41

Table 2. Continued.

	Cycle					
	1	3	4	5	6	7
Day 22	1.00	1.62	4.84			0.65
23	0.67	4.31	2.69			
24	0.86	2.74	2.38			
25	0.76	1.40	1.68			
26	0.86	1.04	1.28			
27	0.81	0.82	0.76			
28	0.90		0.86			
29	0.71		1.01			
30	0.76		1.07			
31	0.96		0.97			
32			1.04			

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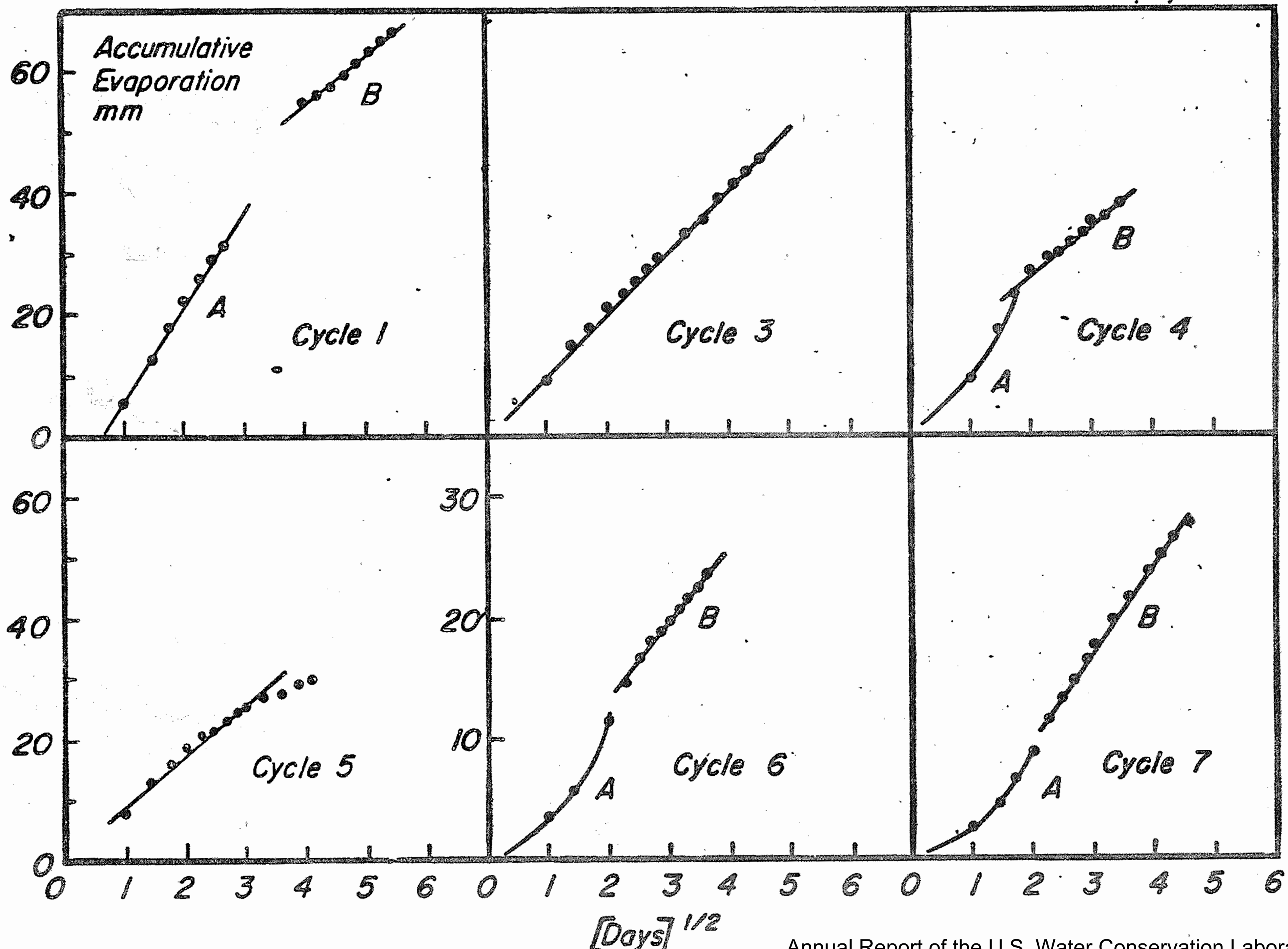


Figure 1. Evaporation accumulated during drying cycles versus square root of elapsed time in days.

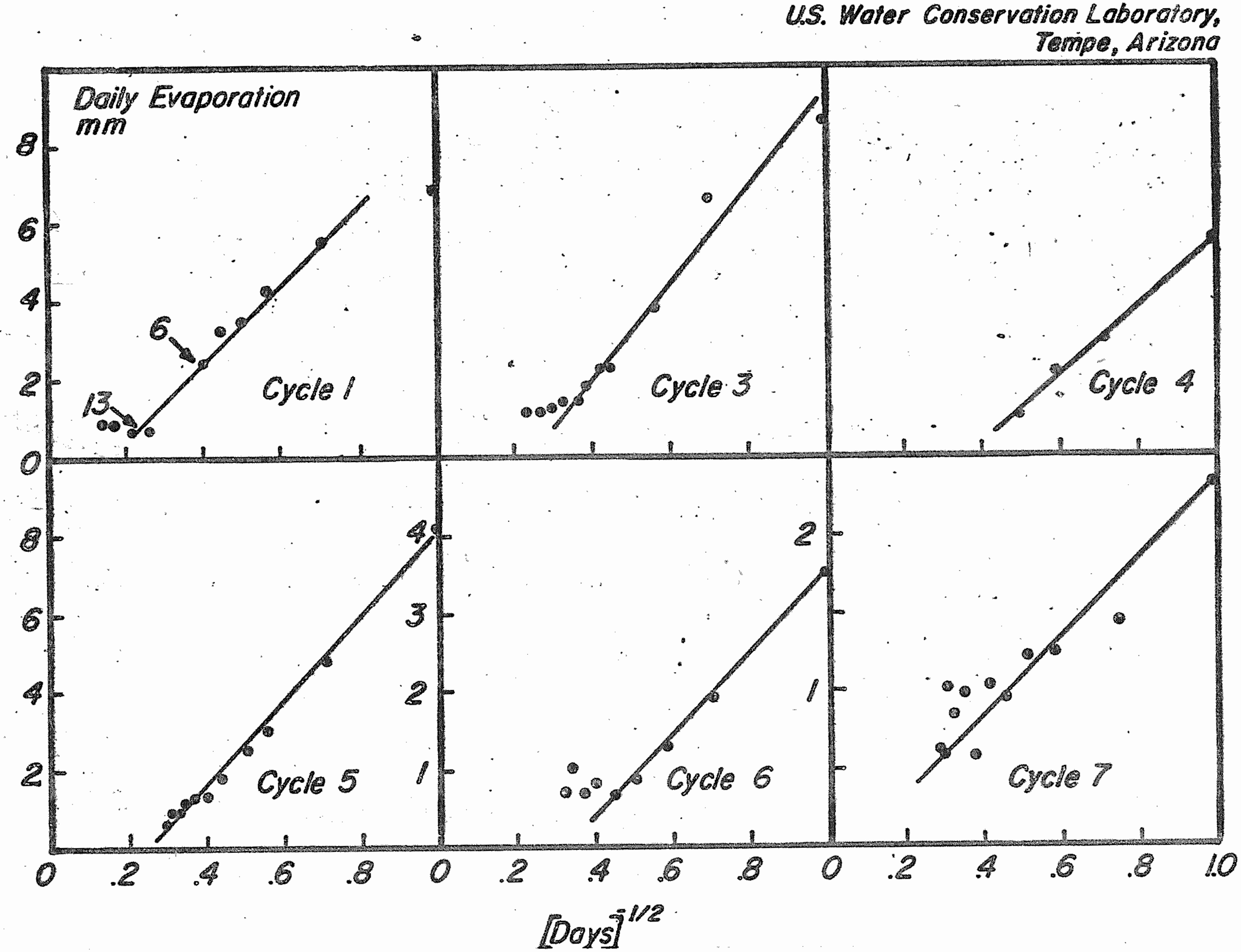
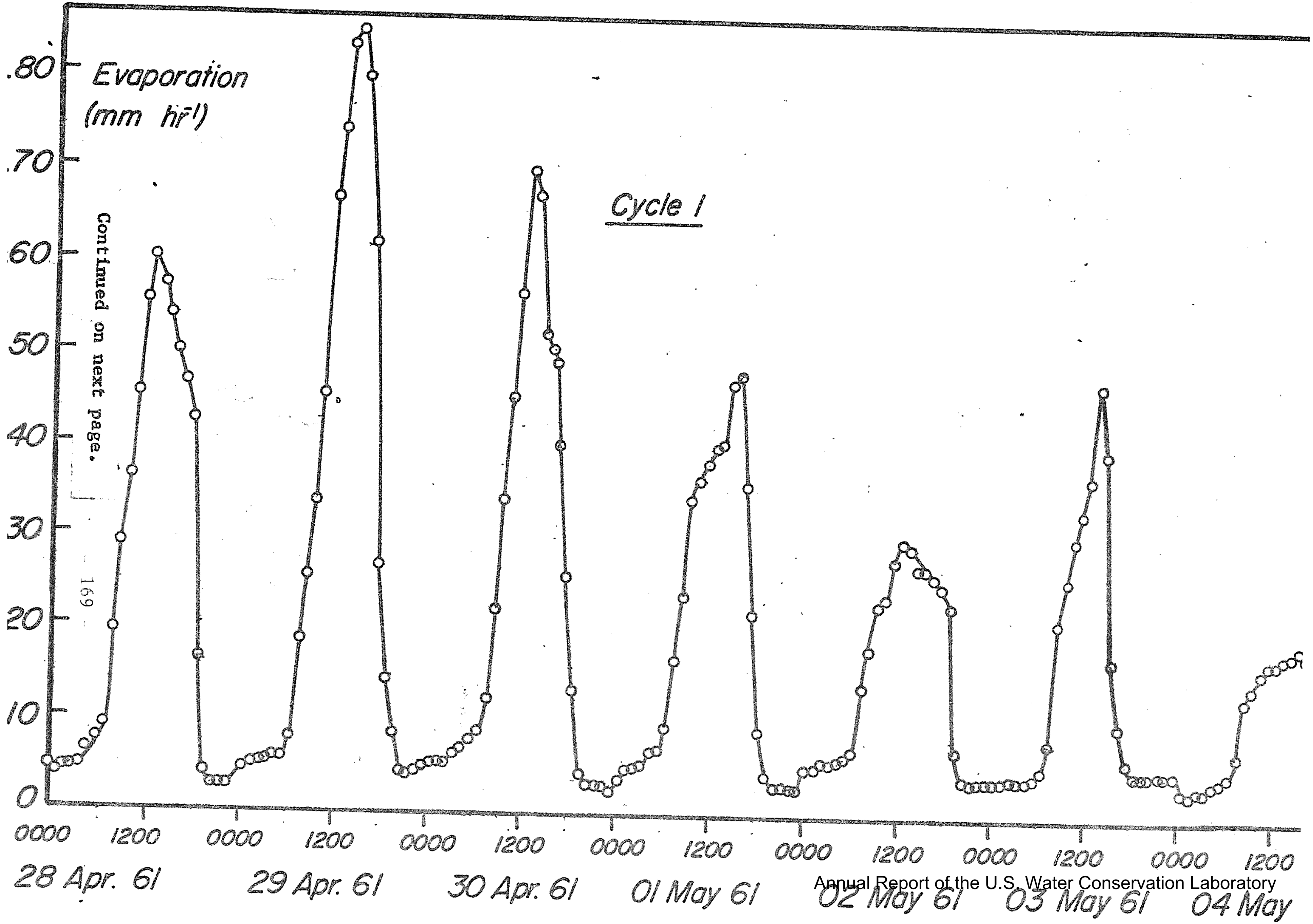


Figure 2. Daily amount of evaporation during drying cycles versus inverse square root of elapsed time in days.



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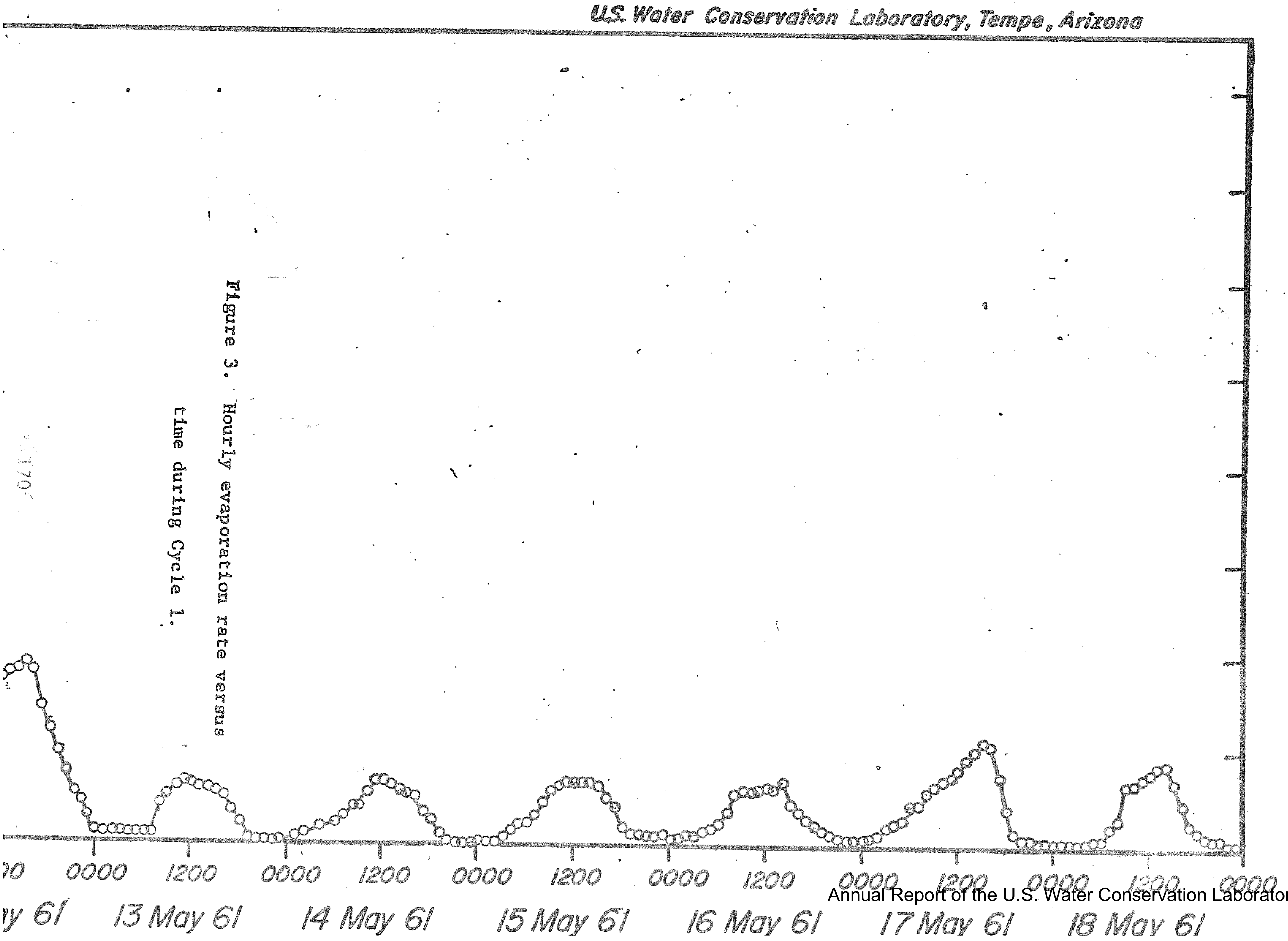
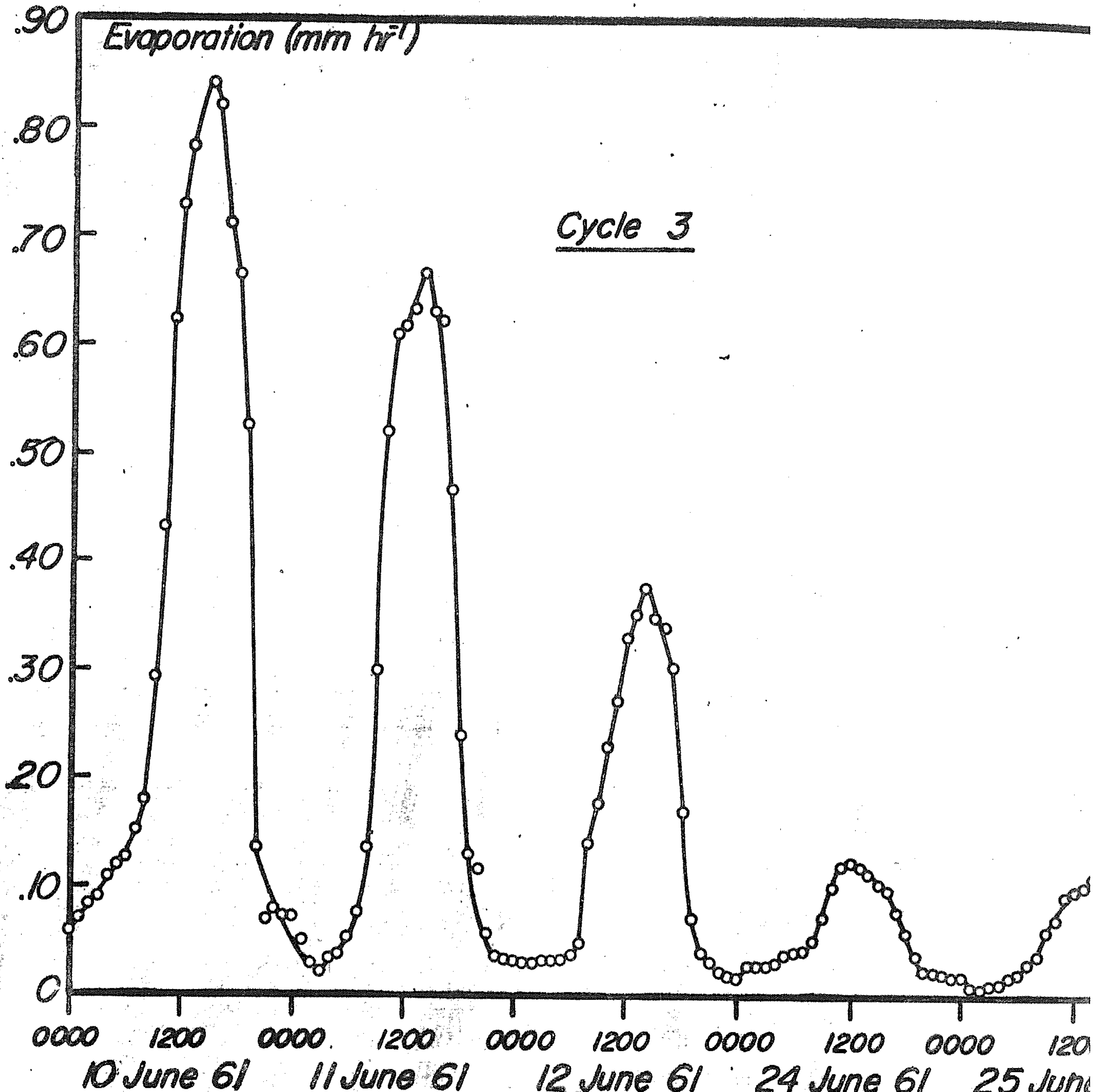


Figure 3. Hourly evaporation rate versus time during Cycle 1.



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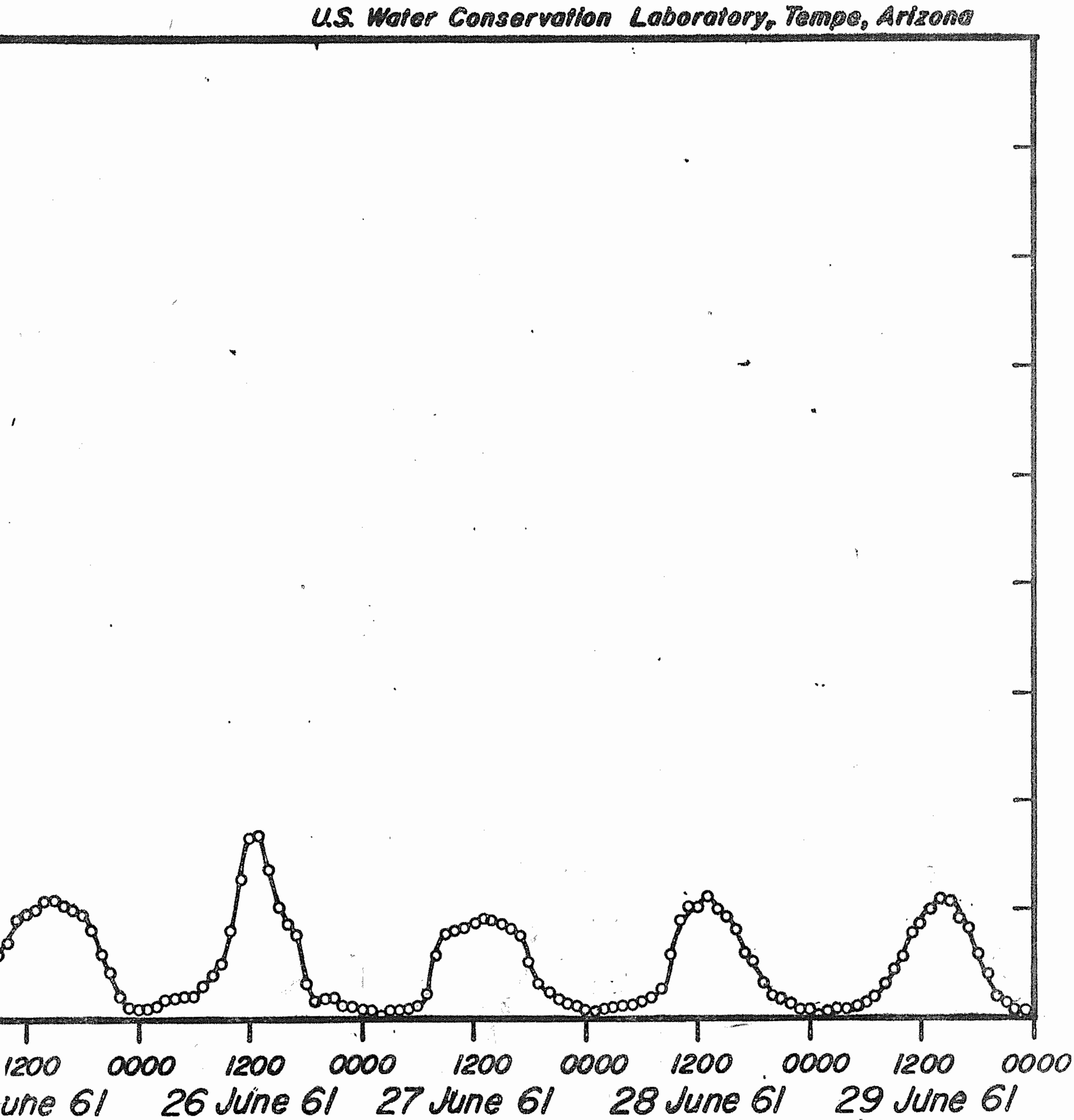
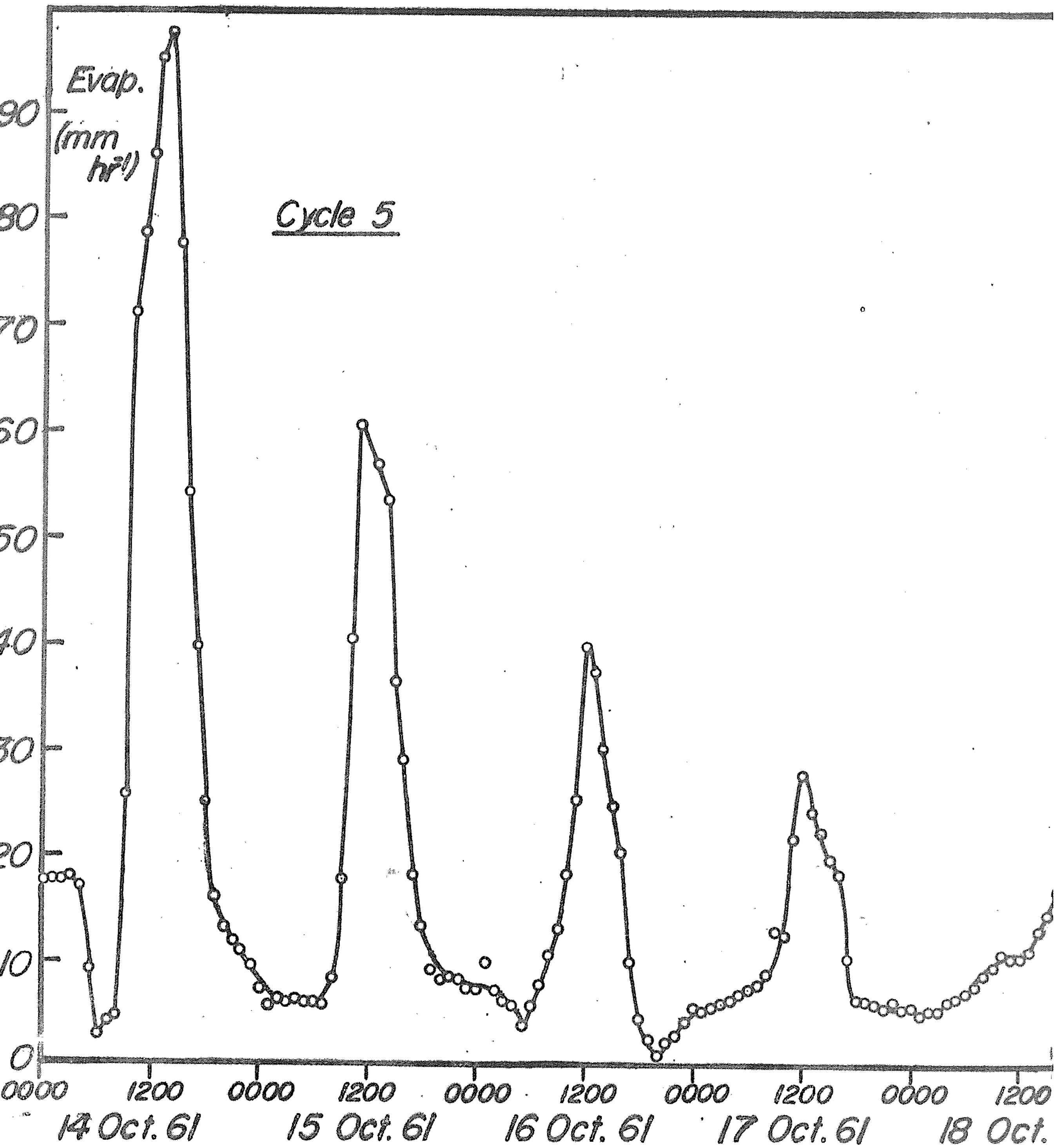


Figure 4. Hourly evaporation rate versus time during Cycle 3.



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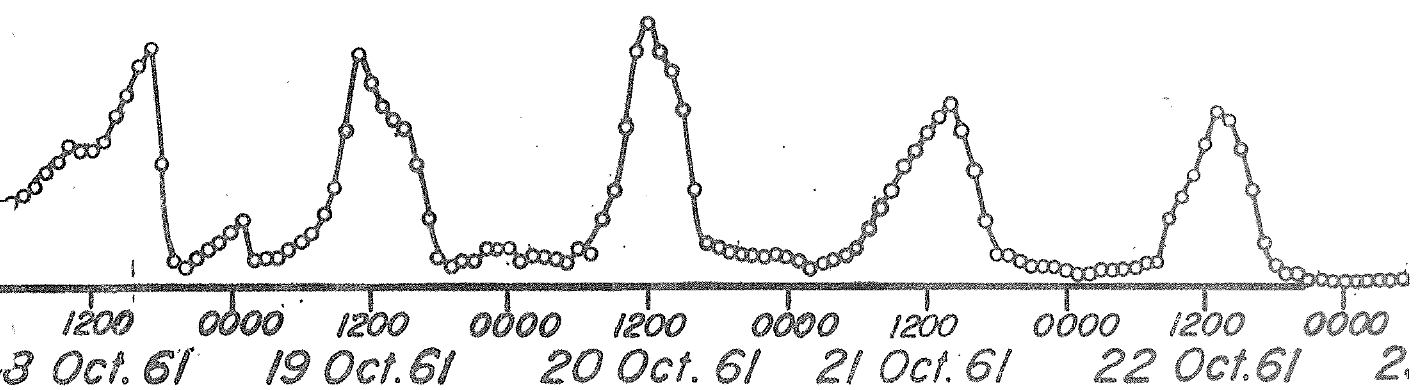

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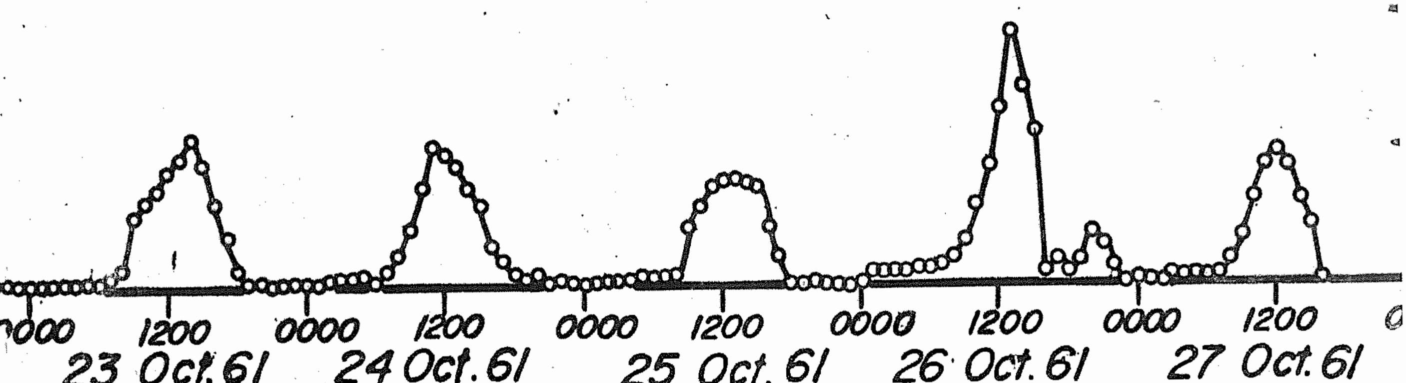
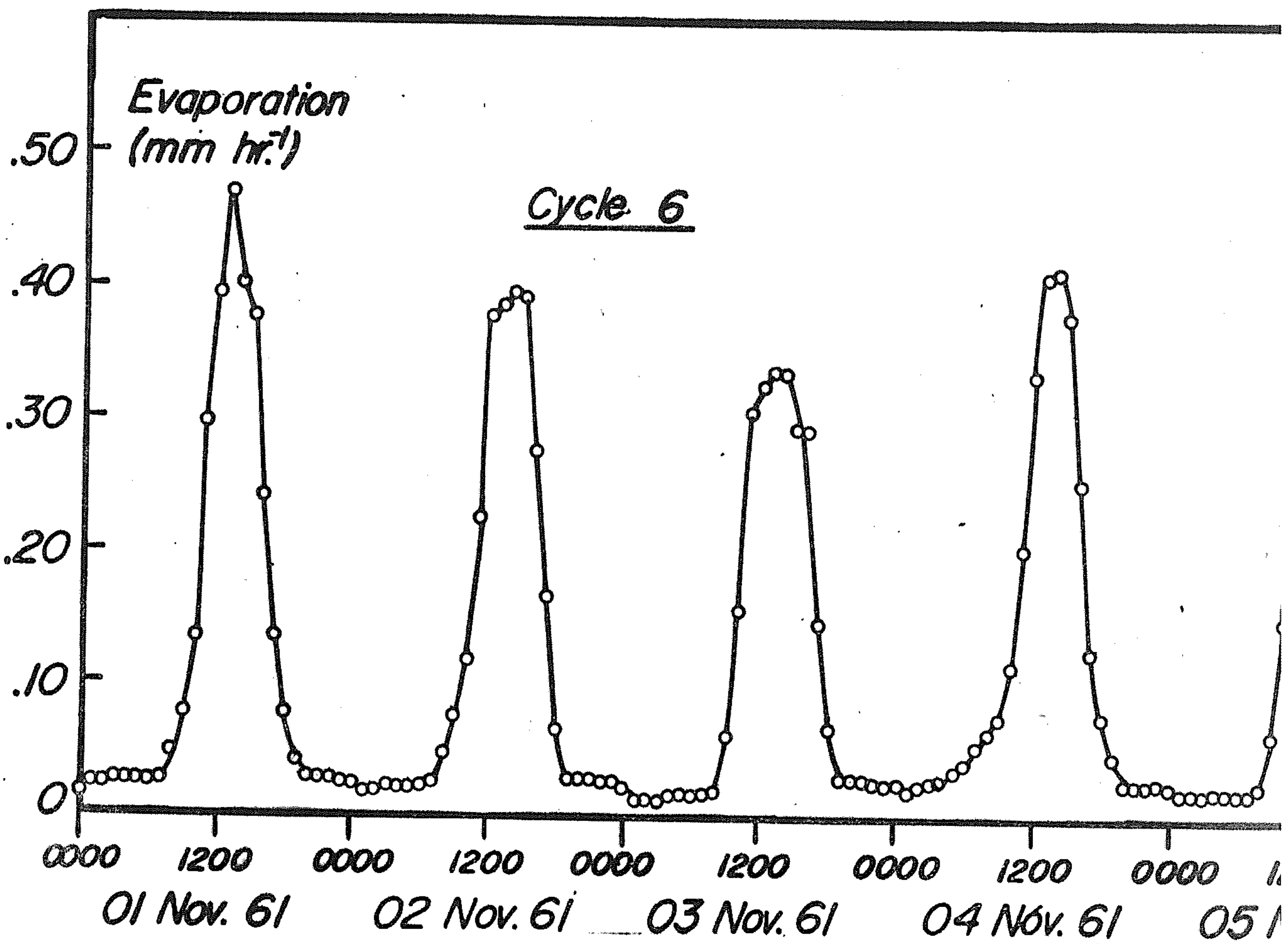


Figure 5. Hourly evaporation rate versus time during Cycle 5.



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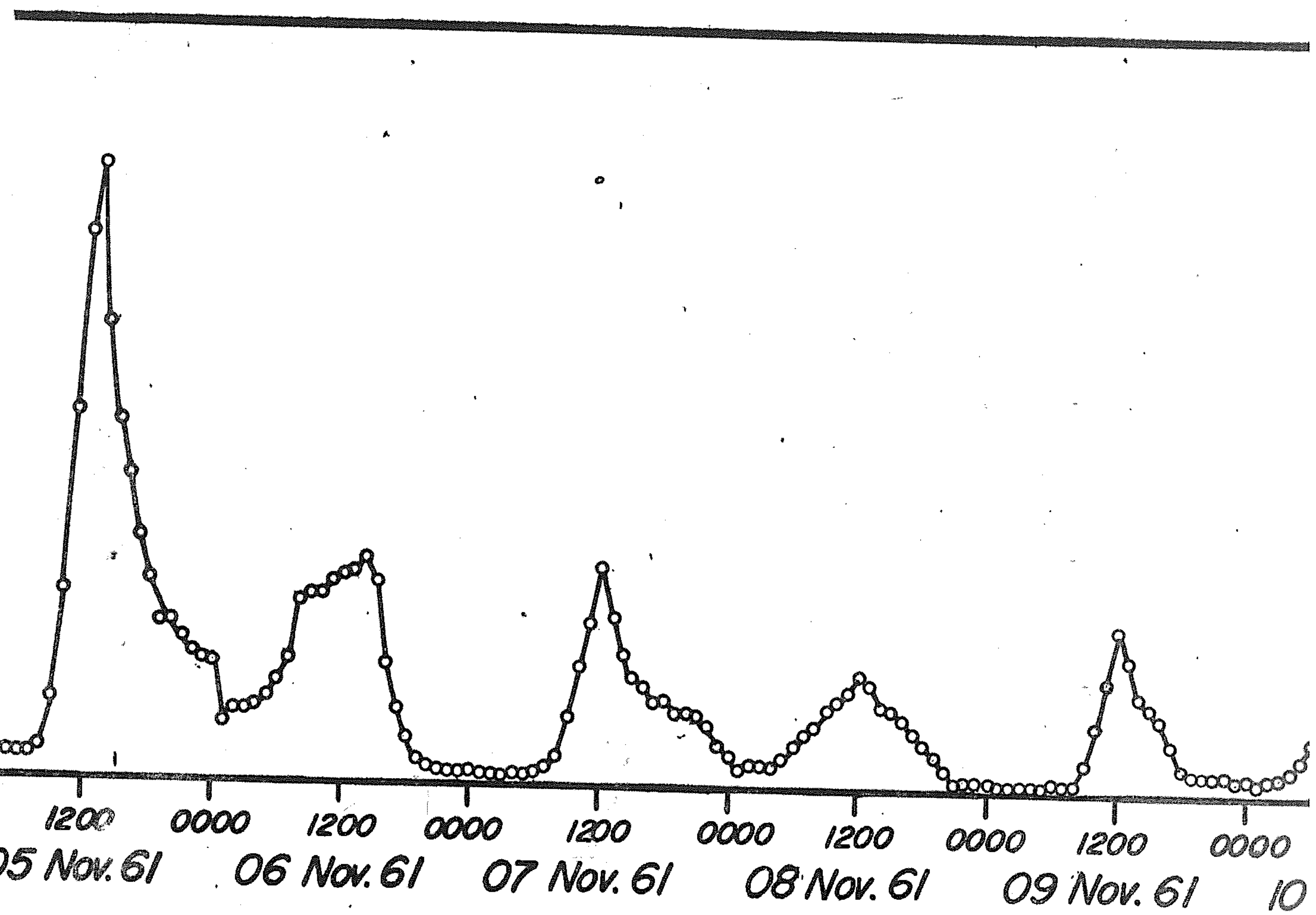

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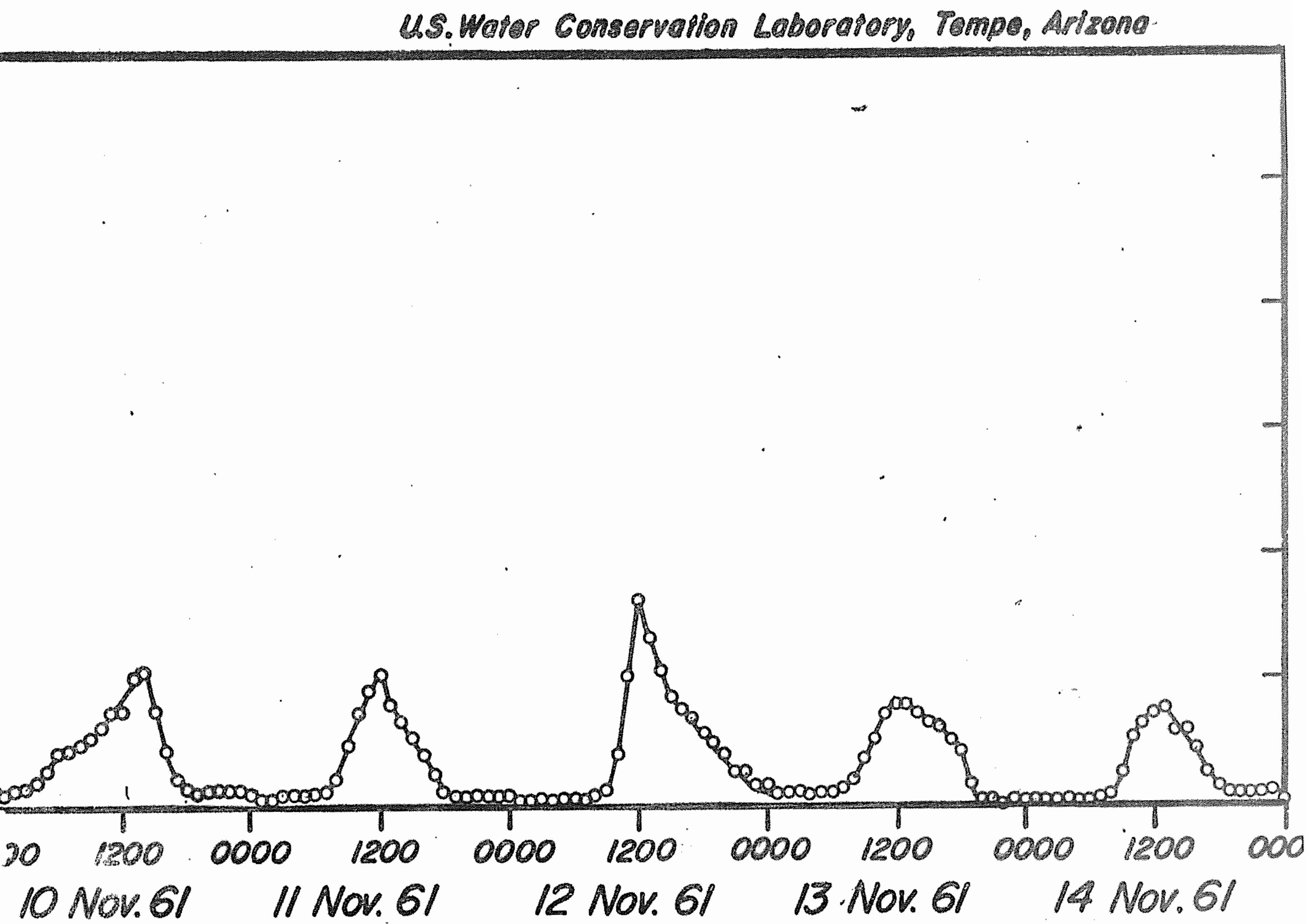
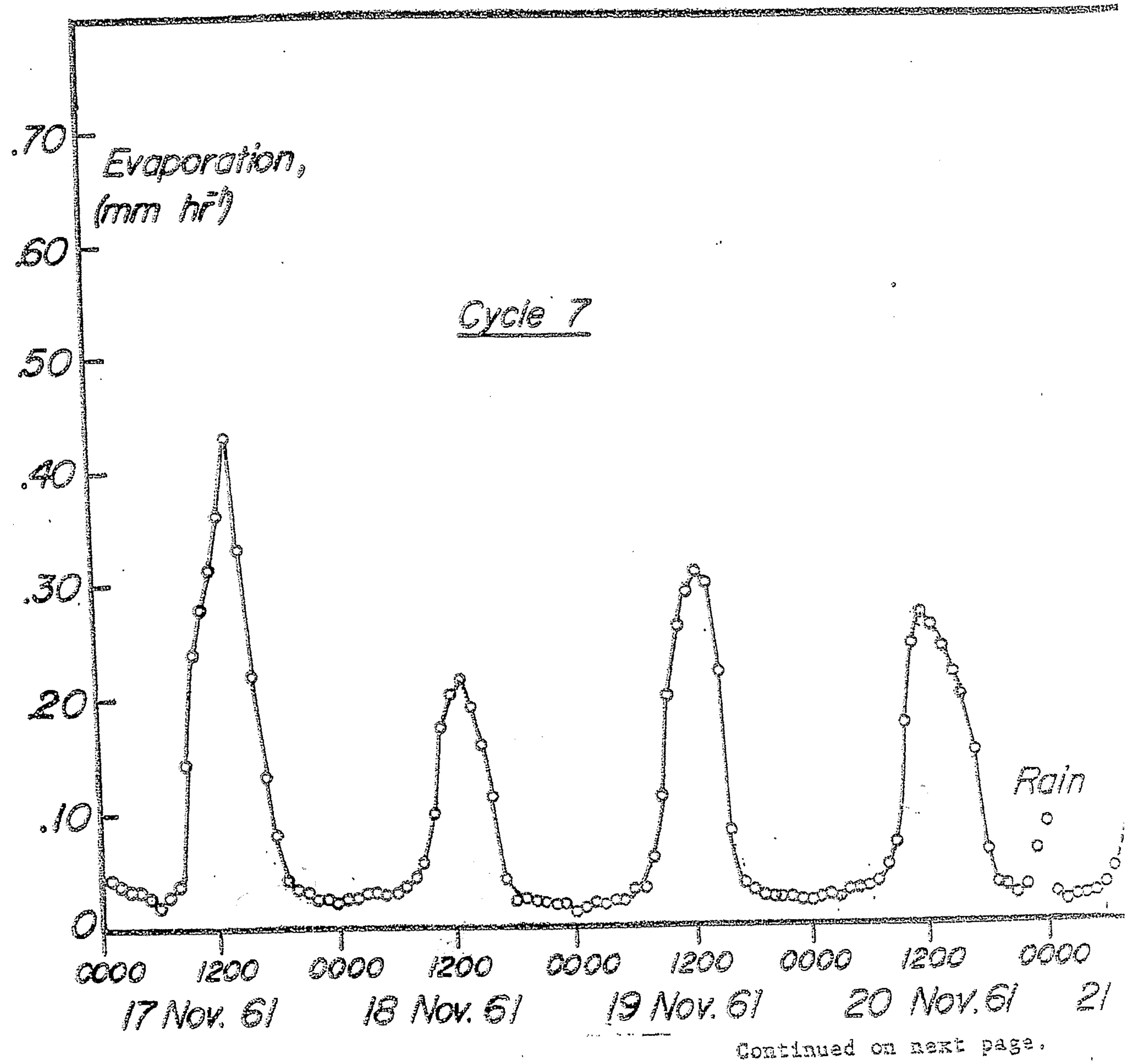


Figure 6. Hourly evaporation rate versus time during Cycle 6.



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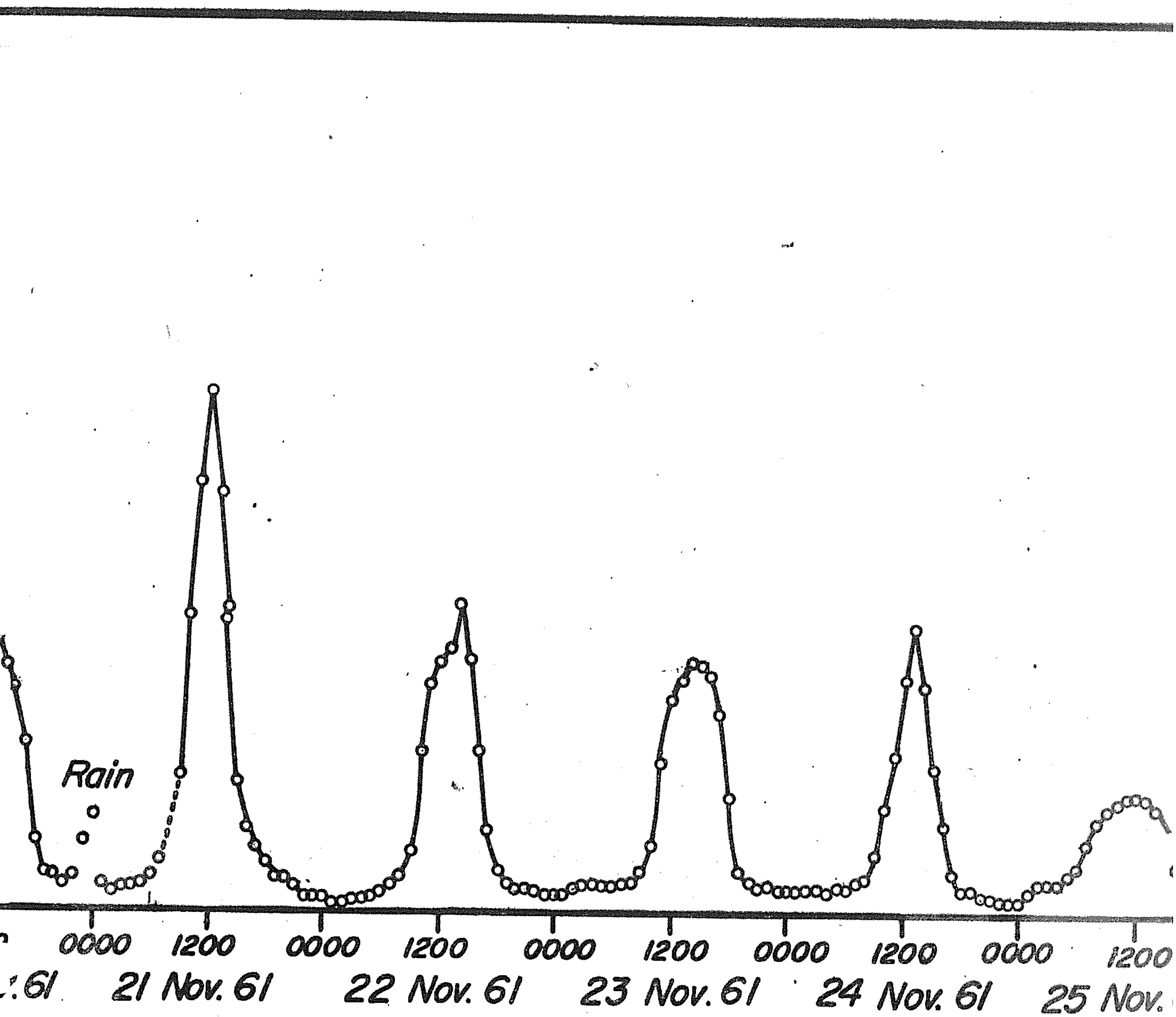

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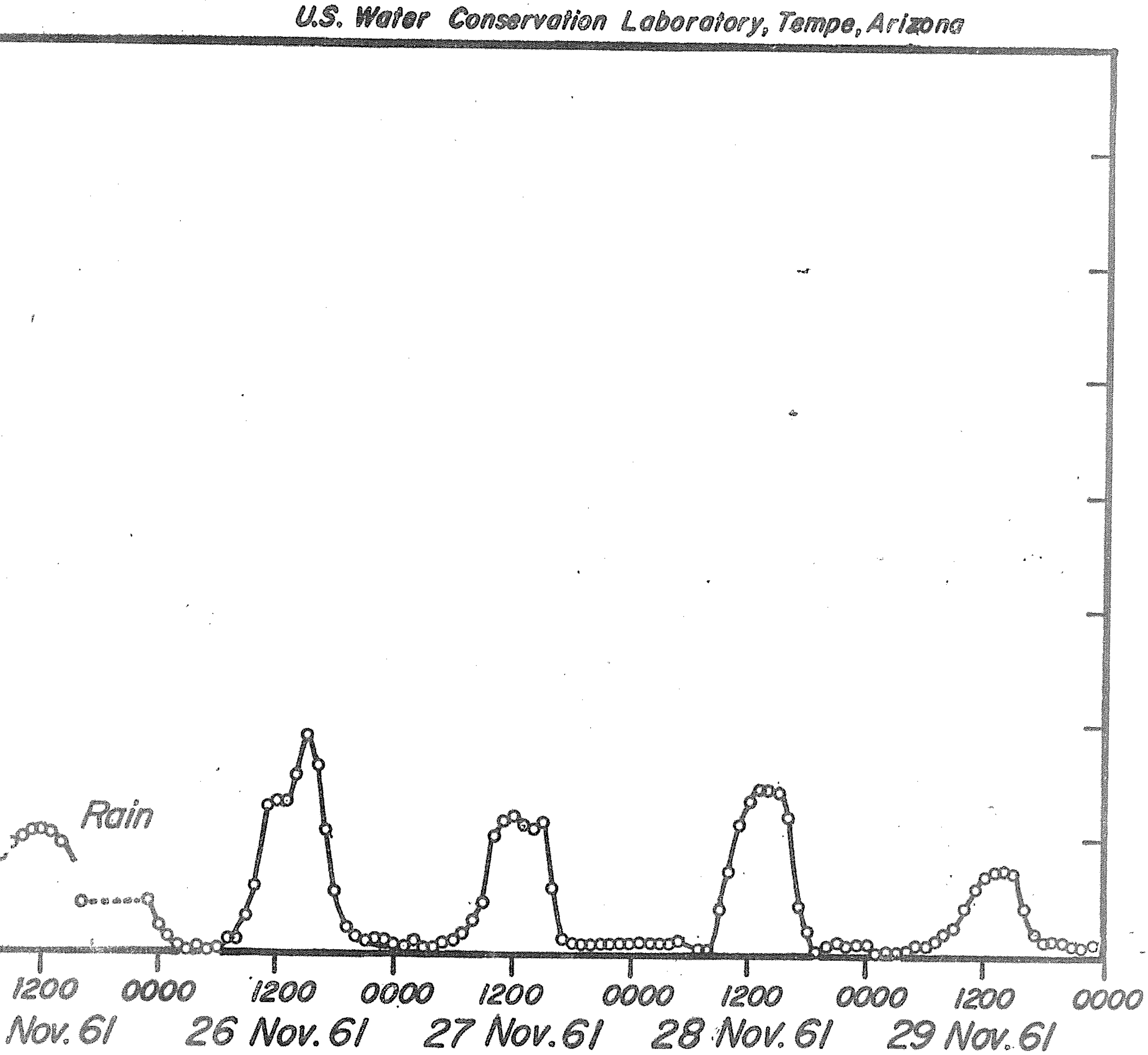

Figure 7. Hourly evaporation rate versus time during Cycle 7.

PART IV. COMPARISON OF EVAPORATION AND SENSIBLE HEAT FLOW AS FOUND WITH LYSIMETERS TO VALUES DETERMINED WITH A FLUXOMETER TECHNIQUE

INTRODUCTION:

A fluxometer is an instrument whereby the sensible heat and evaporation of a surface or object is evaluated by enveloping it in a container and noting the changes in the properties of the air mass as it flows over or by the object of study. This technique has been known for a considerable period of time, particularly in the measurement of transpiration on intact plants. A new version of this principle particularly adapted to the measurement of evaporation and sensible heat flux over a bare surface was developed at the Institute of Atmospheric Physics of the University of Arizona in Tucson, Arizona by Hodges, Yarger, and Sellers. The instrumentation and an account of the theory of the apparatus is given in an article, "A new approach to the measurement of evaporation rates of the sensible heat flux from bare soil or short grass," by C. N. Hodges, D. N. Yarger, and W. D. Sellers of the University of Arizona. At present this report is available in preprint form only.

For details of the construction and operation of this equipment one is referred to the above source. In brief, the instrument consists of two tunnels made of thin polyethylene through which air is swept at a constant and known rate. One of the tunnels is provided with a polyethylene bottom to prevent any migration of moisture from the surface of the study into the tunnel. The other tunnel is open at the bottom. The measurement of evaporative flux consists in measuring the difference in relative humidity, as measured with wet and dry resistance thermometers, between the air that flows through the closed tunnel and the air that flows through the open tunnel. This difference, when converted to moisture content of the air multiplied with the flow rate through the tunnel provides the rate of moisture that migrated from the surface into the air stream per unit of time.

By noting the difference in air temperature at the beginning of the open tunnel and at the end of the open tunnel and by multiplying this difference with the specific heat of air and the flow rate it is also possible to obtain an estimate of the sensible heat that is transferred from the surface into the air or vice versa as the case may be. The flow rate is determined by means of a Pitot tube in a plexiglass cylindrical section of the flow path which had been calibrated previously. By interchanging sensor elements and hose connections, bias that might originate from systematic differences in temperature indication or in air flow through the two separate tunnels is avoided. Measurement of the temperature is made continuously at frequent intervals and an apparatus has been constructed to obtain a record of the temperature in digital form by means of a self-balancing potentiometer, a decimal digitizer and a Clary paper tape printer. The air flow through the system is obtained by means of a vacuum cleaner.

The entire apparatus is portable in the sense that it is not permanently tied down to any site. On the other hand it consists of a number of components and 110 AC power is required for its operation. Nevertheless, using a suitable generator and provided access with a vehicle is possible to the site of measurement, this apparatus could be used in a great number of locations and the interpretation of the data is considerably simpler than anything that would involve profile measurements and application of turbulent transfer theory.

Although the theory of the equipment involves a number of assumptions which are reasonable and are discussed to some extent in the article listed above, the crucial aspect is whether or not the evaporation and sensible heat flux of the area under study will be appreciably influenced by the presence of the apparatus and by the artificial creation of a unidirectional air flow of constant velocity over the surface. While it is possible to theorize on this particular question it was felt that it would be very much worthwhile to compare measurements obtained with the fluxometer directly with those that were obtained by means of the lysimeter installation at the U. S. Water Conservation Laboratory. If such studies would indicate reasonable agreement between the two types of measurements and satisfactory operational characteristics of the apparatus, the technique would certainly warrant further study and possible application.

PROCEDURE:

In cooperation with Dr. Sellers of the Institute of Atmospheric Physics a series of simultaneous measurements was arranged on September 11 through 14, 1961 on the lysimeter field. At the outset on September 11 the entire field was quite dry and the equipment was set up first with the open tunnel on one lysimeter and later in the day with both tunnels on an area close to one of the lysimeters. On September 12 the lysimeters were wetted with 30 mm of water. Two equal areas, which were located over heat flow discs buried in the field, were also wetted by means of rectangular sheet metal dividers with 30 mm of water. After this water had disappeared from the surface a series of simultaneous measurements was made starting at about 1200 on September 12 and continued until 0100 the next morning and resumed at 0640 until 1140 on September 13. At that time a severe dust storm and rainstorm interrupted the measurements. At the same occasion a considerable amount of rainfall averaging about 10 mm fell on the area. The next morning on September 14 measurements were resumed. The area had been uniformly wetted the day before and the soil did not visibly dry out until the earlier part of the afternoon. The lysimeters were somewhat slower in indicating dryness of the surface layer. These measurements were carried out until approximately 1700 of September 14.

During the period of observations with the fluxometer the lysimeter weight was recorded every 5 minutes. In addition, net radiation was measured over one of the lysimeters and over the open tube of the fluxometer. Also, heat flux in the soil at a 5 cm depth in the lysimeter and under the fluxometer was recorded as well as incoming solar radiation as measured with an Eppley and the direction and speed of the wind at 1 m height.

RESULTS:

Data obtained under dry soil conditions on September 11 were rather limited. The first part of the data which was obtained with the open tunnel on the lysimeter was not considered reliable because of the presence of the lysimeter rim and the fact that the lysimeter was actually somewhat higher than the surrounding area. Coupling these facts with the artificial air flow through the tunnel it was felt the air sampled by the tunnel would not be representative of the air actually present over an undisturbed lysimeter. For a period of approximately 2 hours comparative data between the lysimeter and fluxometer in an adjacent area were obtained. These data gave an evaporation rate varying from 0.2 mm per hour to about 0.1 mm per hour with the fluxometer whereas the lysimeter indicated an evaporation rate varying from 0.1 mm per hour to zero mm per hour. The relative difference between the two indications is large but in terms of absolute amounts and in view of the precision of both methods it is felt that this discrepancy is not necessarily too serious. On the other hand radiation balance obtained over the lysimeter indicated a heat flow into the air varying between 0.2 ly min^{-1} and zero ly min^{-1} whereas the fluxometer indicated values between 0.5 ly min^{-1} and 0.2 ly min^{-1}. There are relatively large values, compatible with the dryness of the soil and the high rate of radiative flux, and must be considered a consistent and serious discrepancy between the two methods of measurement.

On the second and third day of the experiment (September 12 and 13) more representative data were obtained. Measurements were started around the noon hour on September 12 after the areas of measurement had been wetted. Measurements were interrupted for approximately 7 hours during the night between the 12th and 13th. The fluxometer apparatus was working without difficulty and a continuous record was obtained on the radiation heat flux, windspeed and evaporation from the lysimeters.

The radiation and heat flux data, which are not given in detail here, demonstrate that there is little if any significant difference in the net radiation over the lysimeters and over the soil that was covered with the fluxometer. This would tend to indicate that the presence of the fluxometer does not affect the radiation balance nor the part of net radiation which is used for heating of the soil or vice versa. A comparison of the evaporative flux as obtained by the two methods is presented in Figure 1. The open circles represent the evaporation rates in millimeters per hour as evaluated every 15 minutes from the smooth lysimeter record. The solid circles indicate the data computed from the fluxometer. Figure 1 shows a reasonable general agreement even though it is obvious that, as a whole, the fluxometer gives data that are lower than the lysimeter figures. This tendency becomes particularly obvious during periods of higher windspeed when advected energy might be used for evaporation. This effect is particularly noticeable during the period between 0900 and 1100 on September 13. As the wind record indicates, a very sharp increase in wind preceding the rainstorm, which occurred at 1130, caused a very sharp rise in the evaporation rate as measured from the lysimeter. Radiation was unaffected until approximately 1130. Also, as the windspeed declined at 1100, just prior to the onset of the storm, the evaporation from the lysimeter reacted immediately with a similar decline. Qualitatively, the fluxometer data show the same trend but during the high evaporation period a very large discrepancy occurred between the lysimeter and fluxometer data. To a lesser extent, similar behavior may be noted during the evening of September 12 between the hours of 2000 and 2200. A plot of the sensible heat flux in the air as measured directly with the fluxometer (solid circles) and as found by difference from the lysimeter evaporation data and the radiation balance is given, together with the windspeed, in Figure 2. The relative discrepancies between the fluxometer data and lysimeter data are quite a bit larger than in Figure 1. It seems again as if the fluxometer data do not reflect changes in sensible heat flux that are associated with changes in windspeed. This is most evident on the data of September 13.

The data of September 14 should have been the best of the entire set since the field was uniformly wetted by 10 mm rain. Unfortunately, the fluxometer equipment was not working very well and condensation had also occurred in the tubing. Therefore, a limited amount of good data were obtained on this day and they are not presented in a continuous manner as was done for the 12th and 13th. A summary of hourly data for all four days, including those for the 14th that were considered reliable, are given in Figure 3. In this figure, the evaporation measured with the fluxometers is compared with that measured with the lysimeter. Again this figure confirms the notion that even though the two methods are in general agreement, the individual deviations, even for hourly periods, may be large. With two exceptions, fluxometer data are generally lower than those obtained with the lysimeter. In order to make another comparison, that is not directly affected by the evaporation from the lysimeters, a plot is shown in Figure 4 of the net radiation over the fluxometer as compared to net radiation over the lysimeter. This shows, in conformity with an earlier statement, a fair agreement. There is a slight tendency for lower net radiation over the fluxometer than over the lysimeter. In Figure 5 a plot is made of the sum of sensible heat flux and evaporative flux as measured by the fluxometer and the sum of net radiation and heat flow into soil as measured over the lysimeter. This plot, in conformity with Figure 3, shows a general agreement but individual large discrepancies.

It may be argued that conditions over the lysimeter and over the field where the fluxometer was located might not have been exactly the same. Indeed it is possible to think of a more ideal condition under which this comparison could have been made such as following a heavy irrigation or rain. Nevertheless, it is felt that most of the evidence points to the fact that the fluxometer is unable to follow changes in evaporation and in sensible heat flux that are directly attributable to changes in windspeed and possibly in forced convection or wind induced turbulent transfer. Even though this may be partially overcome by adjusting the air speed in the fluxometer tunnel, it is difficult to see how this can be done objectively during the course of measurement. The conclusion is drawn at this time that the fluxometer technique may be useful when it is not possible to make another type of evaluation of evaporative flux. On the other hand the data will have to be looked at with considerable caution. Also, it seems desirable in the future to repeat a comparison of this kind under conditions that leave as little doubt as possible as to the meaning of the discrepancies that might be found between the two methods.

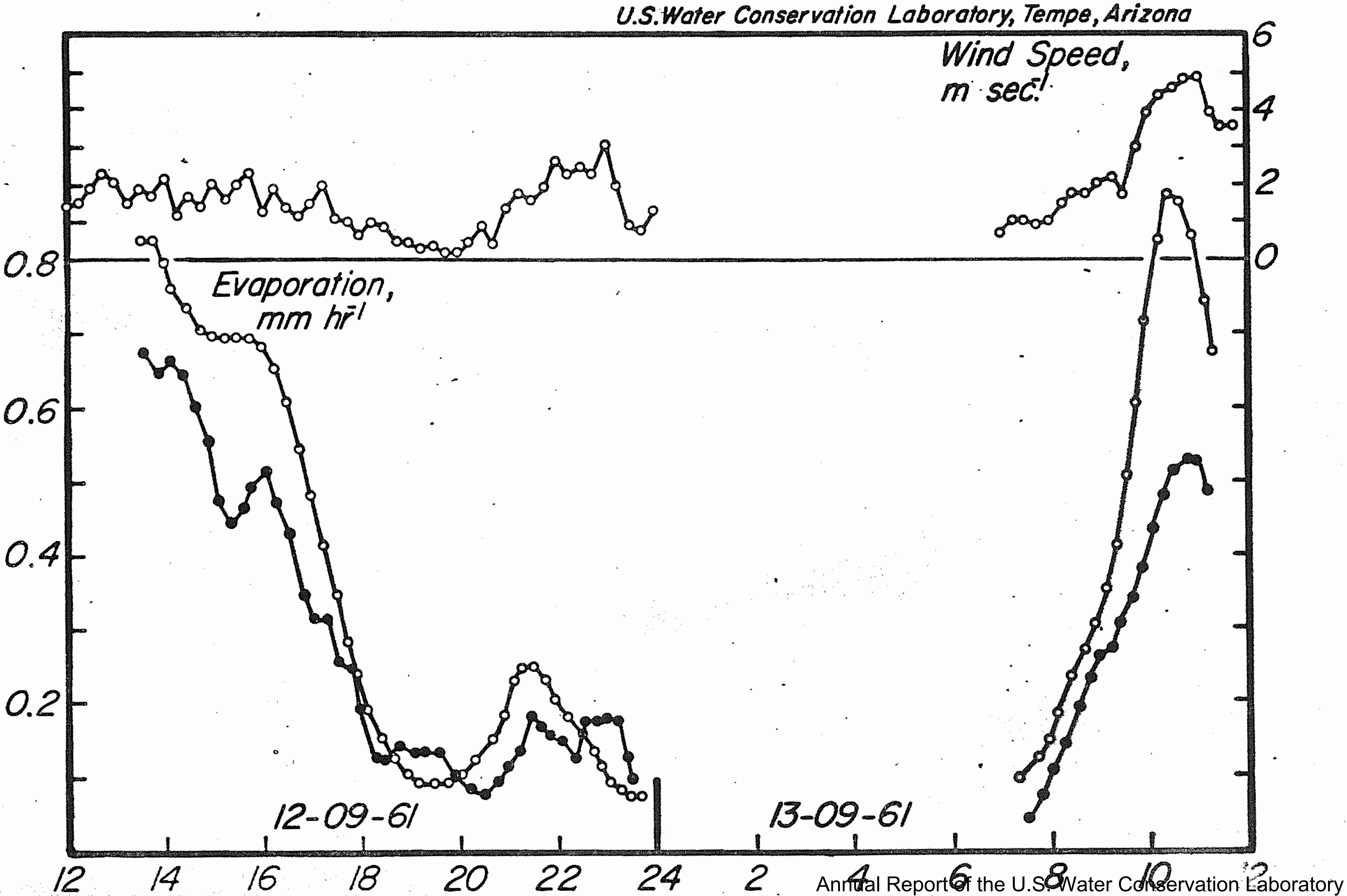

Figure 1. Evaporative flux as measured with the lysimeters and a fluxometer.

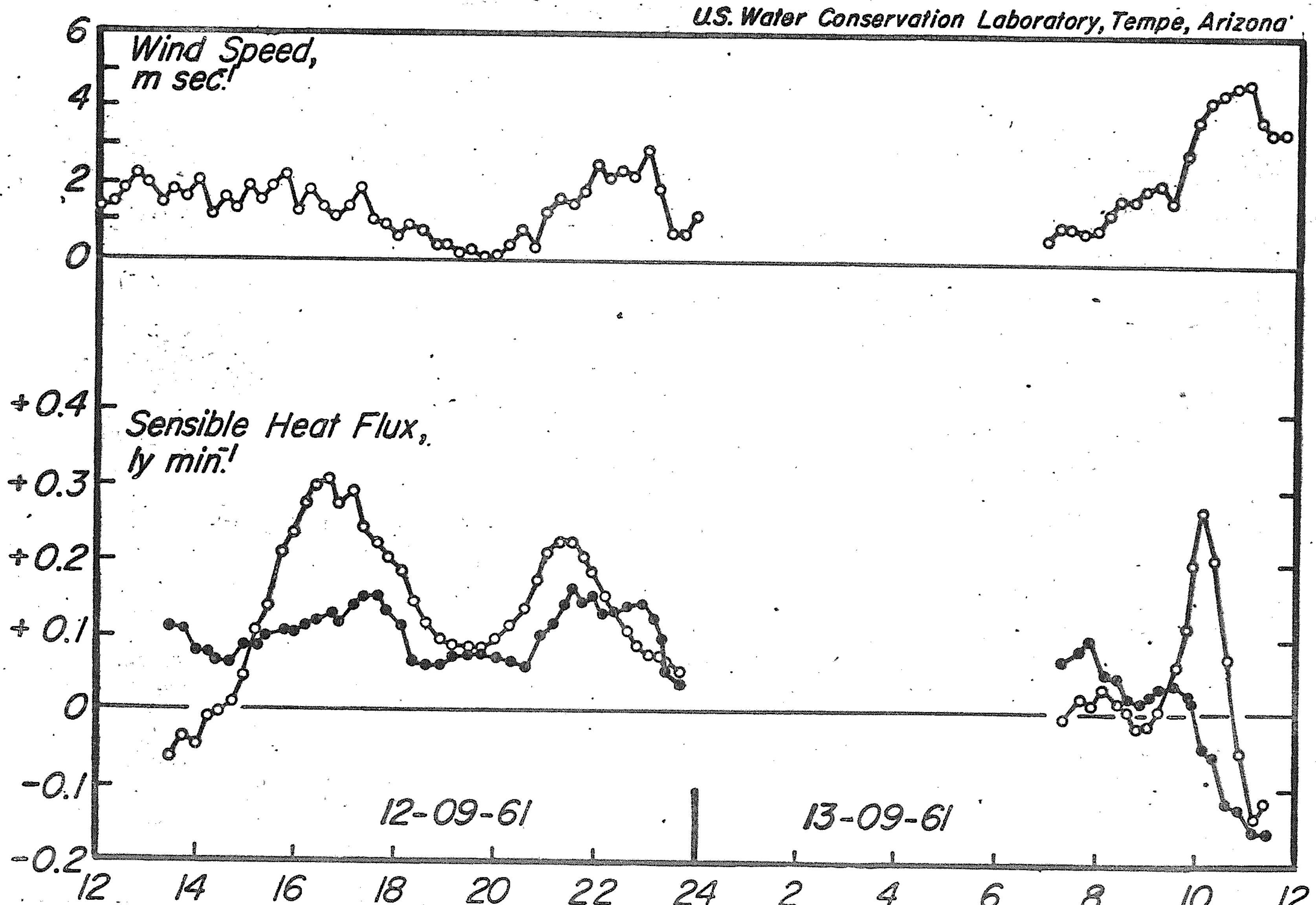

Figure 2. Sensible heat flux into the air as measured with lysimeters, net radiometers, and heat flux plates on the one hand and a fluxometer on the other.

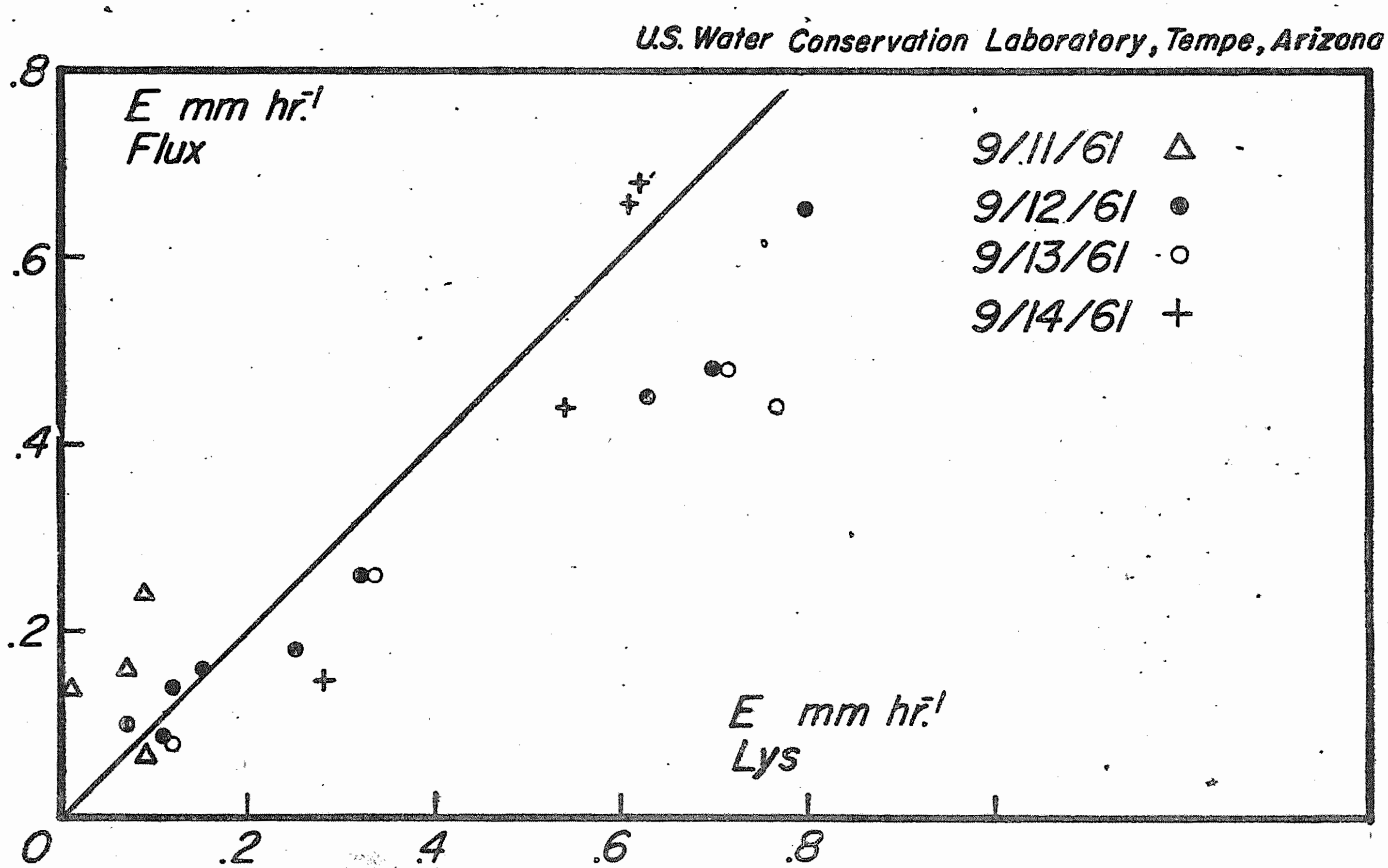

Figure 3. Comparison of hourly values of evaporation as measured with lysimeter and fluxometer.

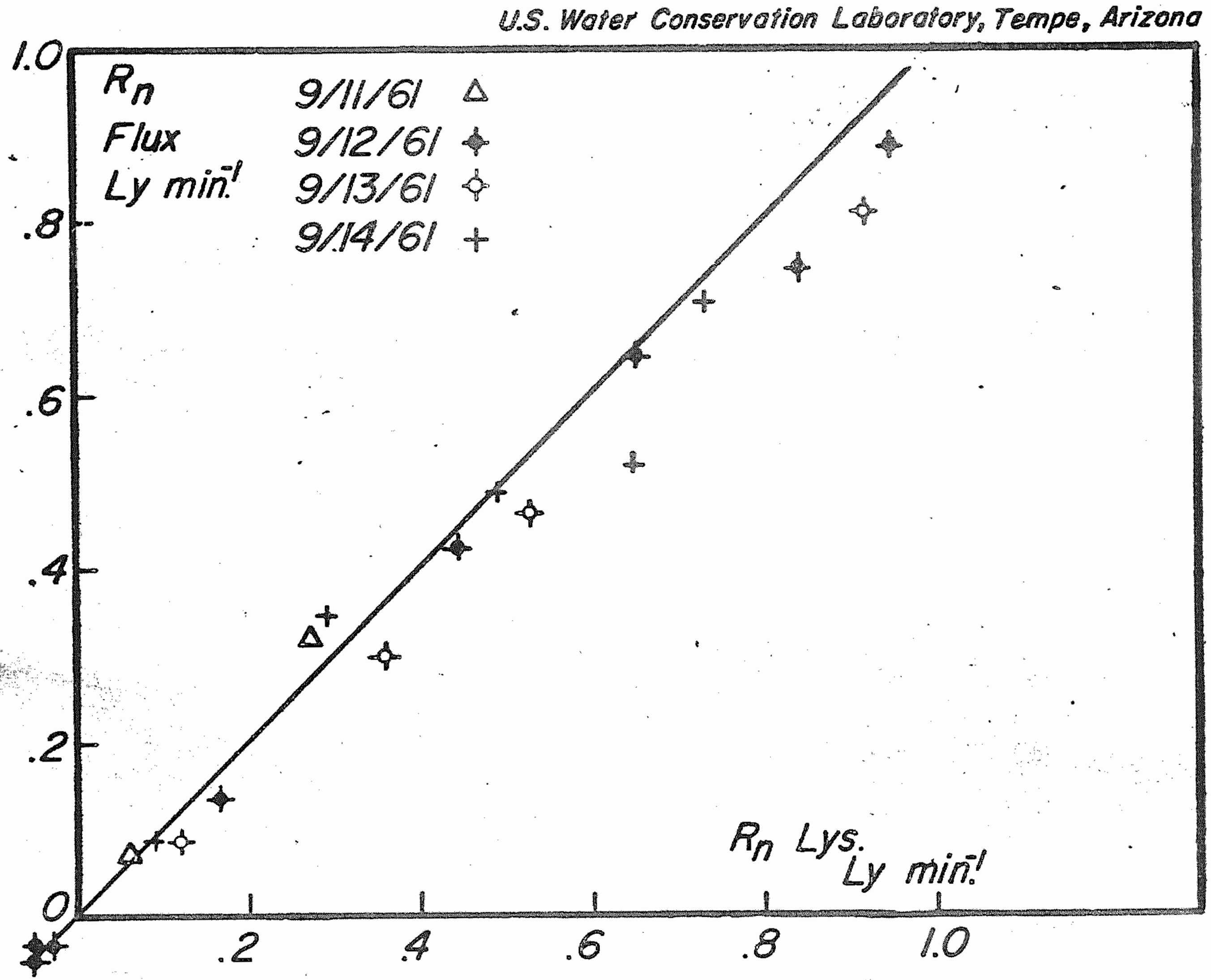

Figure 4. Comparison of net radiation over the lysimeters and the fluxometer as hourly averages for three days.

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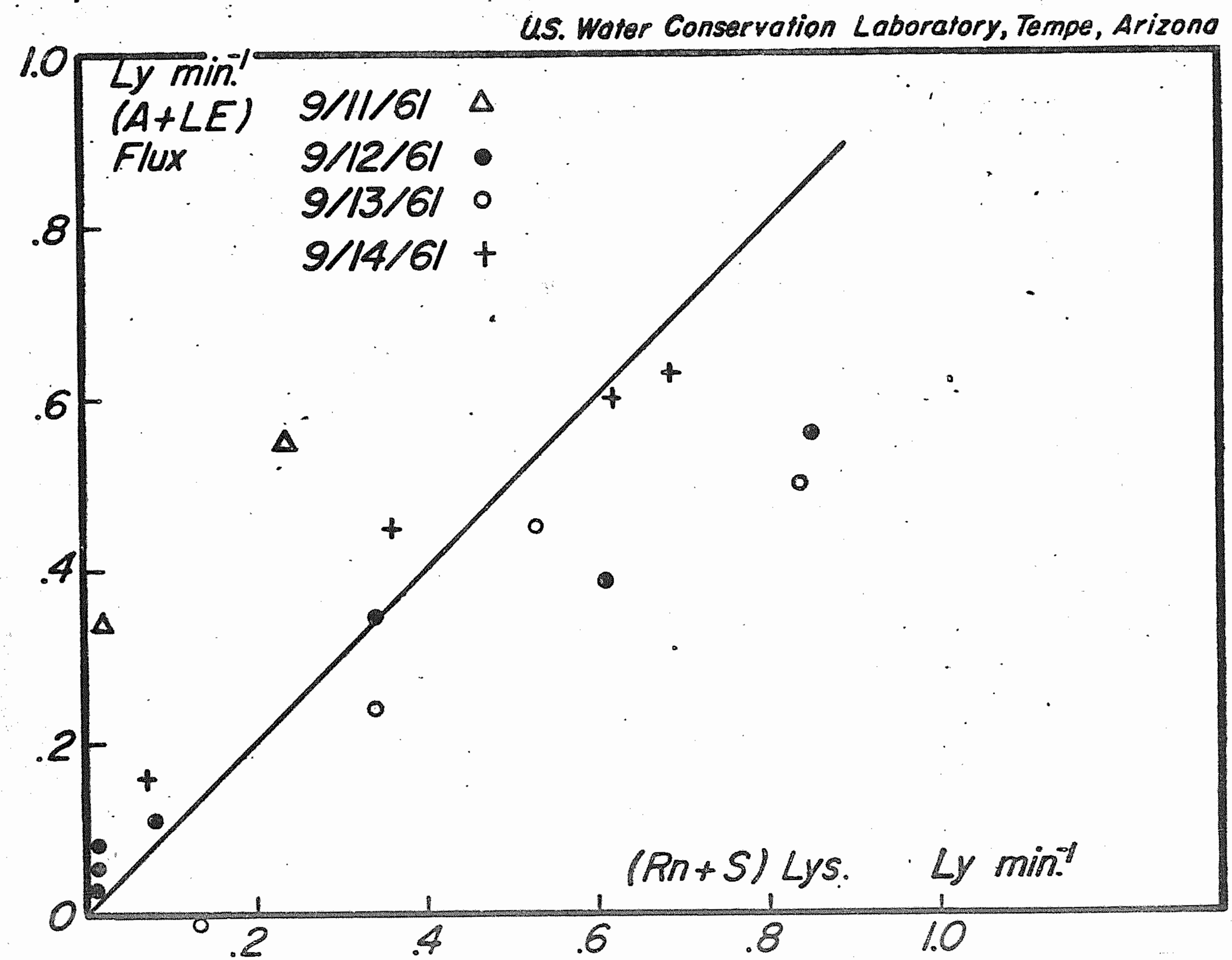


Figure 5. Comparison of sum of evaporative and sensible heat flux from fluxmeter to sum of net radiation and soil heat flux over lysimeter.

GENERAL SUMMARY FOR EXPERIMENT:

The lysimeters and surrounding field were kept bare during 1961. Several wetting and drying cycles were studied more or less in detail. Moisture content, pressure potentials, temperature, and soil heat flux were not materially different in the lysimeters than in the surrounding soil. The drainage system and weight recording system performed satisfactorily.

Daily totals of evaporation following irrigation showed a phase of drying during which the accumulated water loss was proportional to the square root of time. However, during prolonged drying cycles the daily total assumed a near-constant value of around 1 mm per day. At any stage, evaporation showed a pronounced daily variation, approximately in phase with solar radiation. Nighttime values were measurable immediately after wetting but became near zero when the surface was quite dry.

A comparison between a fluxometer technique for measuring evaporation and sensible heat flux and lysimeter data in September showed qualitative agreement. However, the effect of wind on the flux of vapor and heat was not accurately accounted for by the fluxometer technique.

PERSONNEL: C. H. M. van Bavel, R. J. Reginato, L. J. Fritschen, J. L. MacIntyre, J. Evans, K. Mullins, A. Sandecki

TITLE: SOIL TREATMENT TO REDUCE INFILTRATION AND INCREASE PRECIPITATION RUNOFF

LINE PROJECT: SWC 4-gG 3 CODE NO: Ariz.-WCL-7

INTRODUCTION:

See Annual Report - 1960.

PROCEDURE:

Procedures were the same as outlined in the 1960 Annual Report except as follows:

Initial screening of water repellent materials is done in 5 inch diameter petri dishes. Soil is lightly compacted in the dishes, treated with the material under test and dried. Water repellency is then tested by placing drops of water on the soil surface. This simple procedure, which seems adequate, greatly reduced the amount of work required to screen water repellent materials.

Measurement of infiltration and detention of water sprayed on the 30 x 30 inch soil trays was determined by weighing the trays before and after spraying. Previous measurements based on the difference between water applied and runoff were not sufficiently accurate because of difficulties in measuring the water applied.

One 5 x 20 foot field plot was covered with butyl rubber sheeting to serve as a 100 per cent runoff standard for comparison with the other plots.

Construction of 50 x 50 foot field test plots was begun. These plots are on a 5 per cent slope and drain into individual plastic lined temporary holding reservoirs. Water is drained from the reservoirs by fiberglass wrapped perforated plastic pipe and is measured by standard household type water meters. One plot is covered with butyl rubber sheeting and is used as a 100 per cent runoff standard for calculating the effectiveness of the other plots with lower cost treatments.

RESULTS AND DISCUSSION:

A number of materials have been evaluated since the 1960 report. Most of them have proven unsatisfactory. The best materials evaluated to date are an asphalt emulsion designated as S-1, and two water repellent materials designated as R-1 and R-9. We have not found any single material which both stabilizes and waterproofs soil for costs as low as those obtained by applying separate stabilizers and water repellents. Our basic treatment consists of separate spray applications of a soil sterilant, a soil stabilizer, and a water repellent. No investigation of soil sterilants has been made and we have relied upon the work of other investigators.

<u>Soil stabilization:</u> Several materials, such as formulations including calcium acrylate or sodium silicate, were tested and found unsatisfactory because of excessive cracking and shrinking upon drying. Information obtained from manufacturers indicated that other materials advertised for soil stabilization would be unsuitable for water harvesting because of short life or high cost. Asphalt emulsion remains the best material we have tested, although some questions concerning it have not yet been answered.

The optimum application rate of S-1 is dependent upon a number of factors including porosity of the applied coating. This was investigated by applying the material at various rates to the surface of a wet sandy loam soil in 3 inch diameter plastic cylinders and measuring the rate of evaporation of water from the cylinders. The soil was uniformly compacted to a 5 inch depth in the 6 inch tall cylinders and the same amount of water was applied to the soil in all cylinders before treatment. After treatment the cylinders were placed in a forced draft oven at 40°C and weighed at intervals. The position of the cylinders within the oven was changed every 24 hours. Cumulative weight loss, as a direct measure of evaporation, is shown in Figure 1. An application of 0.10 lb/ft^2 produced a coating which was only slightly porous.

Water running off soil trays treated with S-1 was observed to be colored from a light yellow to a dark brown. The discoloration, believed to be oxidation products of S-1, can be removed by filtering. No taste or odor could be detected. Judicious inquiries have revealed that this discoloration is common in water which flows in small amounts over exposed asphalt. A commercial firm is currently conducting investigations concerning the oxidation products of asphalt emulsions. We believe that the only objection will be on esthetic grounds but are developing a soil treatment which should eliminate any discoloration.

The durability of thin coatings of asphalt emulsions is a major question regarding their own use for long-term soil stabilization. A 5 x 20 foot field plot treated January 5, 1961, with S-1 at 0.05 lb/ft^2 and R-1 at 200 lb/acre is still stabilized by the asphalt over one year later although noticeable deterioration has occurred. This rate is only half that used now. Soil trays treated with the

0.1 lb/ft^2 rate have shown no significant deterioration after one year of exposure. The year old field plot still produces ten times as much runoff as untreated soil, which is about what it produced when new.

Water repellents: Many repellents have been tested and most of them will make soil water repellent. The effectiveness on different soils is variable and tests must be made on soil samples from proposed installation sites. The first repellent tested, a fatty quatenary ammonium salt designated R-1, is still one of the best for our soils. The optimum rate of application is primarily a function of the specific surface area of the soil and should be determined for each soil.

Field plots: Treatments applied to the 5 x 20 plots are listed in Table 1. Plot 2 was covered with butyl rubber after it became apparent that treatment R-4 had failed. Similarly, Plot 3 was used as an untreated check until 9-15-61 when it was treated with S-1. Runoff data from the 5 x 20 foot plots are presented in Table 2. It should be pointed out that these are primarily weathering plots, with more than one treatment on some plots. The slope is less than 3 per cent and the soil surface is rough. Runoff from these same treatments will be considerably higher if the soil surface is smooth and has a greater slope.

The 50 x 50 foot field plots had not been completed as of January 1, 1962. An untreated plot and one covered with 15 mil butyl sheet were completed. Treatment of a third plot was begun but was disked and reshaped because the original surface was much too rough. A 26 foot tapered fiberglass spray boom was designed and constructed to apply sprayable materials, including asphalt emulsions, to water harvesting areas. The boom was field tested and worked very well for applying materials in a uniform 25 foot swath at a rate of 50 gallons per minute. All materials applied to the 50 x 50 foot plots will be applied with this boom.

SUMMARY AND CONCLUSIONS:

Data from laboratory and field tests indicate that the soil stabilizing and waterproofing treatments now under test will last well over a year under our conditions of climate and soils. Asphalt emulsions remain the best low-cost soil stabilizing materials we have tested. One 5 x 20 foot field plot is still producing ten times as much runoff as untreated soil a year after initial treatment, even though the treatment material was applied at one-half the rate we are now using.

Some problems remain. Runoff water from the asphalt plots is sometimes discolored and this problem is under study. Weathering properties of the treatment are not completely evaluated. Findings to date indicate, however, that the present treatment may already be suitable for operational use on water harvesting installations for stock water supplies.

PERSONNEL:

L. E. Myers, G. W. Frasier, C. L. Jenson.

Table 1. Treatments applied to 5'x 20' test plots at Granite Reef.

Plot	Date	Treatment
1	1-5-61	S-1 0.05 lb/ft^2
		R-1 100 lbs/acre
2A	1-5-61	R-4 (a) 235 lbs/acre
		R-4 (b) 113 lbs/acre
2B	5-18-61	30 mil butyl rubber
3A	1-5-61	Untreated
1	8-25-61	Re-treated with R-1 100 lbs/acre
3B	9-15-61	S-1 0.10 lb/ft^2 upper half
		S-1 0.20 lb/ft^2 lower half
4	9-15-61	Untreated
5	9-22-61	S-1 0.10 lb/ft^2 upper half
		S-1 0.05 lb/ft^2 lower half
		R-1 100 lbs/acre right half
		R-8 150 lbs/acre left half

Table 2. Runoff data from 5'x 20' plots at Granite Reef.

Date	Rainfall		Plot #1		Plot #2A		Plot #2B		Plot #3A		Plot #3B		Plot #4		Plot #5	
	Intensity	Total	Runoff		Runoff		Runoff		Runoff		Runoff		Runoff		Runoff	
	in/hr	in	in	%	in	%	in	%	in	%	in	%	in	%	in	%
3-4-61		0.75	.41	54.7	.24	32.0			.03	10.7						
3-28 3-29 -61		0.63	.25	39.6	.03	4.8			.02	3.2						
7-28-61	.15	0.17	.022	12.9			.166	97.6								
8-11-61	.40	0.22	.12	54.5			.209	95.0								
8-14-61	.08	0.25	.008	3.2			.129	51.7								
8-18-61	.25	0.55	.290	52.8			.561	102.0								
8-28-61	.06	0.28	.032	11.5			.29	103.5	.032	11.5						
9-8-61	.08	0.05	.016	32.0			.024	48.0								
9-14-61	.02	0.10	.002	2.0			.064	64.0	.018	18.0						
10-9-61	.02	0.03					.032	106.5								
10-30-61	.02	0.12					.072	60.0			.032	26.6			.035	29.2
11-21-61	.20	0.08	.016	20.0			.072	90.0			.040	50.0			.048	60.0
11-25-61	.10	0.41	.064	15.6			.44	107.3			.161	34.9	.003	0.73	.177	43.2
12-10-61	.10	0.41	.064	15.6			.44	107.3			.161	34.9	.003	0.73	.177	43.2
12-14 12-15 -61	.15	1.025	.369	36.0			1.093	106.6			.353	34.4	.032	3.00	.691	64.4

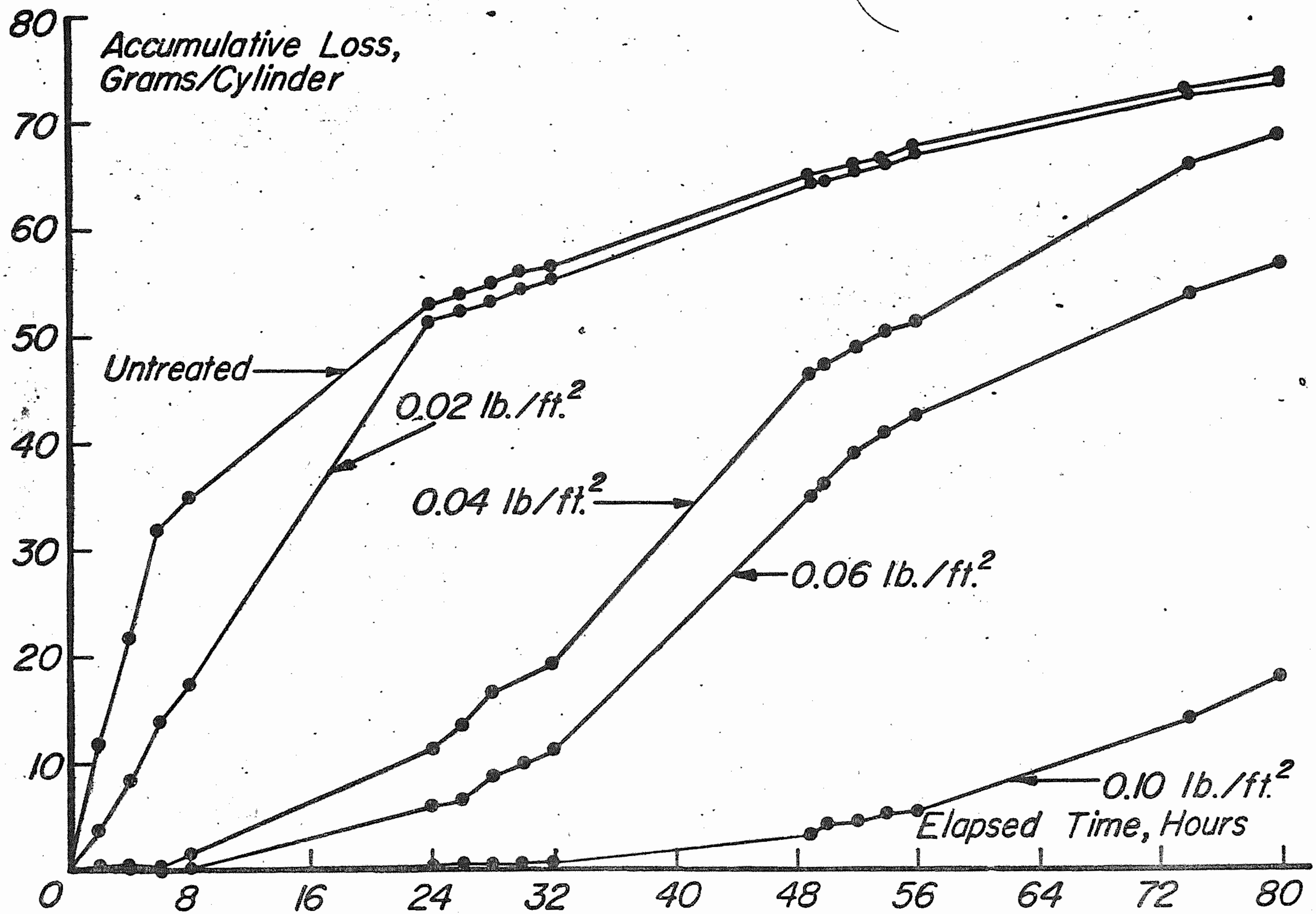


Figure 1. Evaporation from a soil surface treated with asphalt emulsion S-1.

TITLE: ANALYZING GROUND-WATER MOUND FORMATION BY RESISTANCE NETWORK ANALOGS

LINE PROJECT: SWC 4-gG3 CODE: Ariz.-WCL-15

INTRODUCTION:

The conditions under which ground-water mounds may be formed or dissipated are quite varied. Mounds may rise and spread above original water tables if saturated material is already present. If natural water tables are initially not occurring, mounds may form above impermeable strata. In layered soils, perched mounds will develop above layers of reduced conductivity. These layers may be continuous or discontinuous (lenses). If there is internal drainage, stable or equilibrium mounds can develop. In the absence of drainage below the water table, mounds can rise until the entire soil is saturated. The geometry of the flow configurations can be two-dimensional, radial or irregular. The systems can be of restricted or essentially unrestricted lateral and/or vertical extent. The original water table or layers of reduced conductivity upon which ground-water mounds may be formed, can be horizontal or sloping.

Soil properties of direct importance in the behavior of mounds are the hydraulic conductivity and the fillable and drainable porosity. In addition to non-uniform conditions of hydraulic conductivity such as layered soil, soils may be anisotropic with the horizontal conductivity usually exceeding the vertical conductivity. The fillable porosity may be less in the region below the recharge area or other percolation areas than outside this area. Because of hysteresis, the drainable porosity may be less than the fillable porosity. The rate with which water moves downward to the ground-water mound may not be uniform but may vary with respect to location as well as to time. Decreased recharge rates may occur under conditions of prolonged inundation of spreading areas.

Theoretical procedures for analyzing formation, dissipation and equilibrium positions of ground-water mounds below spreading or other source areas, should preferably be able to cope with the spectrum of conditions discussed in the previous paragraph. One tool that could take the various complexities and non-uniformities into account is the electrical resistance network analog. The more important aspects of techniques for analyzing mound behavior by means of an electrical resistance model of the flow system will be discussed in this report. For a complete description, reference is made to (42).

The initial inspiration for this project was furnished by the severe limitations of the horizontal-flow theory, which has formed the basis of several mathematical treatments of ground-water mound behavior. A conference on this subject was held in Fort Collins, December 20-21, 1960, with representatives of the Western Soil and Water Management Research Branch of SWC-ARS-USDA, the U. S. Bureau of Reclamation, and the U. S. Geological Survey.

PROCEDURE:

The technique for analyzing ground-water mounds with a resistance network will be discussed for media with uniform porosity, simplified hydraulic conductivity characteristics, and two-dimensional systems. The same principles can be applied, however, to analyze ground-water mound behavior under more complex conditions and/or axially symmetrical cases. The discussion of the procedure will start with stable or equilibrium mounds, to be followed by moving mounds and approximate equations to predict the rate of rise or fall of the center region of the mound above an original water table.

Stable mounds. Stable-mound conditions can develop if there is some form of escape for the water below the water table or some control level above which the water table can not rise. Stable mounds may develop above semi-permeable perching layers, above discontinuous impermeable lenses, in the vicinity of pumped wells, or if drainage into other basins or outcrops of water tables in sloping fields or natural channels provide some maximum level of the water table above which the water table can not rise.

The problems to be solved for stable mounds may consist of the equilibrium recharge rate at a given height of the center of the mound, or the equilibrium position of the mound for a certain recharge rate. The first question, which may arise in connection with evaluating recharge potentials of agricultural areas (maximum recharge without water logging), is solved by setting up an electrical model of the conductivity conditions on the analog board. Since the position of the mound is only known at the center, assumed elevations are used for the rest of the mound. The input currents representing recharge are adjusted according to the desired recharge distribution while maintaining the proper voltage at the mound center. When the desired recharge distribution is obtained, the electrical potentials at the other network points representing the water table mound are measured. These potentials should correspond with the assumed values for the elevation of the mound. Since complete agreement will usually not occur at the first trial, a second assumed shape must be assumed and the second measured voltages are compared with the second assumed elevations. This process is repeated until agreement between assumed and measured values is obtained.

The second question may arise if it is desired to evaluate the effect of known recharge rates on the shape of the water table. This problem may be solved by evaluating the equilibrium recharge rate for a number of mound positions in accordance with the previous procedure and determining the mound position at the desired recharge rate by interpolation. It is also possible to solve this problem by setting up an electrical model of the system, using assumed elevations for the entire water table mound. Currents representing the desired recharge rates are then applied to the network points and the corresponding electrical potentials along the water table are measured. These potentials should correspond to the assumed elevations of the water table. Since the measured potentials will usually differ at first, a second assumed shape of the mound is represented on the analog and the procedure is repeated until the difference between the last assumed and the last measured shape of the mound is sufficiently small.

Moving mounds. Moving mounds are solved as a succession of steady mounds. The criterion for solution is that the vertical distance of rise for any point of the mound between time t_i and t_{i+1} is equal to the average of the velocities of rise at t_i and

t_{i+1} times the time increment $t_{i+1} - t_i$. This calls for a trial-and-error procedure whereby assumed values are used for the mound at t_{i+1} after the mound at the previous time t_i has been determined. The assumed values for the mound at t_{i+1} are then adjusted until the above criterion is met. With this procedure, the "starting" mound at t_o must be known. In case of the moving mound, this can be the original water table or the restricting layer above which the mound will be formed.

The solution of rising mounds above impermeable layers or original water tables can be checked with the principle of continuity. In the case of the rising mound, this principle is that the volume of water between the mound at time t and the original water table must be equal to the total volume rate of recharge times the period of time t.

Equations. Equations were developed to estimate the rate of rise or fall of the center of the mound above original water tables in relation to the recharge rate, the fillable porosity, the hydraulic conductivity, the width of the recharge facility, and the thickness of the saturated material below the original water table. The equations are based on three assumptions:

1. The flow in the center portion of the mound above the original water table is vertically downward.
2. The rate of rise of the water table some distance away from the recharge facility is negligibly small compared to the rise of the center portion of the mound.
3. The original water table is horizontal.

According to the first assumption, the downward flow at the bottom of the mound where the original water table was located is the same as the downward flow at the top of the mound. According to the second assumption, the gradient at the bottom of the mound where the original water table was located is directly proportional to the pressure head at that point. Thus, for a given system, the gradient per unit pressure head at the bottom of the mound is a constant. This constant, which is called I_Q depends only on the geometry of the system prior to recharge. The factor I_Q was evaluated with the resistance network in relation to the width W of the recharge facility and the original depth D of the saturated material. For a given height of the center of the mound above the original water table, the downward flow velocity in the center in the mound can be calculated with Darcy's equation, in relation to the hydraulic conductivity K, the height H of the mound center above the original water table, and I_Q. The rate of rise of the mound center is then calculated as the difference between the recharge rate V_a and the rate of downward movement below the top of the mound and dividing this difference by the fillable porosity f above the mound. Rates of rise of the mound center calculated with this principle were compared with rates of rise determined by resistance network analog.

RESULTS AND DISCUSSION:

Stable mounds. An example of an equilibrium mound above two perching layers is shown in Figure 1. The bottom of the lower perching layer is assumed to be at atmospheric pressure. At the equilibrium mound position, the volume rate of movement through the perching layers has become equal to the volume recharge rate. The numbers on the left and bottom of the system in Figure 1 represent units of length. The equipotentials are expressed in the same length units and refer to the bottom of the lower perching layers. The streamlines were sketched as orthogonals to the equipotentials. The network interval Δ is one length unit. The width W of the recharge area is 15 length units. The recharge rate V_a is one-half the conductivity of the more permeable material above the perching layers, thus the recharge gradient is 0.5.

An equilibrium mound above a discontinuous impermeable layer is shown in Figure 2. The soil above the impermeable layer is considered anisotropic with the horizontal permeability equal to four times the vertical permeability. The recharge rate is taken as 0.5 $K_{vertical}$ and it is assumed that the water spills freely of the edge of the impermeable layer into unsaturated but permeable material. The broken lines in Figure 2 represent intermediate mound positions as the mound is forming in the initially dry soil above the impermeable layer. The numbers on the broken line refer to values of $\frac{Kt}{fW}$ (see next paragraph). In addition to soil anisotropy, the fillable porosity was also considered non-uniform with the fillable porosity below the recharge area being 25% of the fillable porosity adjacent to the recharge area.

Moving Mounds. In characterizing the time position of successive mounds the usual parameter $\frac{Kt}{f}$, which has the dimension of a length, has been scaled to the width W of the recharge area so as to yield the dimensionless term $\frac{Kt}{fW}$. Thus, if for a certain recharge installation K is 1 meter per day, f is 0.1, and W is 10 meters, a value of $\frac{Kt}{fW}$ of 20 on the ground-water mound would mean that this is the ground-water mound position reached after (20 x 0.1 x 10)/1 = 20 days.

An example of a flow system for a rising mound is shown in Figure 3. The recharge rate V_a equals K in this case, and the ground-water mound is formed above an original water table overlying saturated material of infinite or very large depth compared to the width W of the recharge installation. The $\frac{Kt}{fW}$ - value for the mound in Figure 3 is 0.667. If W is 150 meters, K is 0.5 meters per day, and f is 0.1, the mound would reach this position in 20 days. Figure 4 shows the results of network analyses of rising mounds above original water tables for different rates of recharge and different ratios of W/D. The numbers on the water-table mounds again represent values of $\frac{Kt}{fW}$. The distance of rise, h, is expressed in terms of the ratio h/W. The horizontal distances X are also expressed in terms of ratios to W.

<u>Equations</u>. The equations resulting from the three assumptions under PROCEDURE are

$$\frac{Kt}{f} = \frac{H_t}{\frac{V_a}{K} - 1} - \frac{2.3}{I_Q\left(\frac{V_a}{K} - 1\right)^2} \log\left[I_Q\left(1 - \frac{K}{V_a}\right) H_t + 1\right] \qquad (1)$$

for the rate of rise of the mound, and

$$\frac{Kt_r}{f_d} = \frac{2.3}{I_Q} \log \frac{H_m}{H_t} + H_m - H_t \qquad (2)$$

for the rate of recession of the mound after cessation of the recharge.

In these equations, H_t is the height of the mound center above the original water table at t, H_m is the distance of the mound center above the original water table when recession begins, f is the fillable porosity, f_t is the drainable porosity, and t_r is the time elapsed since the beginning of recession. The term I_Q was evaluated by resistance network analog and can be evaluated from Figure 5. In this figure, I_Q, which has the dimension of 1/length, is multiplied by W for dimensionless expression. For uniform media, $I_Q W$ is only a function of W/D. According to equation (2), complete recession of the mound to H = 0 would require infinite time. The following expression gives the relationship for 90% recession of the mound

$$\frac{Kt_{r,90\%}}{f_d} = \frac{2.3}{I_Q} + 0.9\ H_m\ .$$

Examples of application of the equations are presented in (42).

The assumption of no rise of the water table at some distance from the recharge area obviously implies an equilibrium position of the mound. The stable height H_∞' of the mound center above the original water table is obtained by equating the argument of the logarithm in equation (1) to zero, yielding

$$\frac{H_\infty}{W} = \frac{1}{I_Q W\ (\frac{K}{V_a} - 1)}\ .$$

In cases where there is a certain maximum level for the water table at some distance from the recharge area, this equation can be used to estimate the equilibrium height of the mound above this control level. For closed systems without internal drainage, equilibrium conditions obviously do not occur and the application of equation (1) is limited to H_t-values that are smaller than H_∞, for instance, to H_t-values up to 0.9 H_∞.

The validity of equation (1) was determined by comparing results obtained with this equation with the results of the network analysis in Figure 4. The results of this comparison (Figure 6) show excellent agreement for the fast and slow recharge rate at large depths of original saturation (W/D = 0). Since increasing W/D from 0 to 1 affects I_QW very little (Figure 5), similar agreement can be expected to exist for all W/D-values less than 1. The agreement for W/D = 3.75 is reasonable, for W/D = 7.5 the agreement is poor. For the latter case, the horizontal flow components in the center region of the mound are no longer negligible which invalidates the first assumption. The results in Figure 6 would indicate that the approximate equations are valid as long as W/D does not exceed 4.

Limitations of the assumption of horizontal flow. According to the horizontal-flow assumption, which has formed the basis of several analytical approaches regarding ground-water mound analysis, the volume rate of flow q_X per unit length at distance X from the center of the recharge area is

$$q_X = KD \frac{dh}{dX} .$$

The limitation of this equation becomes evident by considering extreme values for D, i. e., infinity and zero. When D is equal to infinity, the equation yields a q_X also of infinity. This means zero-resistance to lateral flow and, consequently, a zero-rise of the mound no matter how high V_a may be. If, on the other hand, D is zero, the equation also yields a q_X of zero. This means no lateral movement at all and a rectangular or cylindrical on-the-spot build-up of the mound. Both cases are in obvious conflict with actual behavior of ground-water mounds. The horizontal-flow assumption can thus be expected to underestimate the rate of rise of the mound if D is relatively large, and to overestimate the rise if D is relatively small.

Figure 5 shows that reducing D from infinity to W (increasing W/D from 0 to 1) reduces I_QW from 1.27 to 1.16, or a change of less than 9%. For practical purposes therefore, the effect on I_Q of increasing D becomes insignificant when D has reached a value in excess of W, or D can be considered infinite as long as D is greater than W. The same relation is true for radial flow systems where D can be considered infinite when D equals or exceeds the diameter of the spreading area (22). The above equation of the horizontal flow assumption, however, shows a continued effect of D on q_X, which could lead to serious errors.

SUMMARY AND CONCLUSIONS:

A technique for analyzing ground-water mound behavior under recharge or other source areas with a resistance network analog is presented. The principles of the technique are applicable to rising, stable, and falling mounds for two-dimensional or radial flow systems. The procedure enables taking into account conditions of non-uniformity in soil conductivity, porosity, and recharge rates as well as complex geometry, boundary, and drainage conditions. Moving mounds are handled as a succession of stable mounds. The technique may be used for studies of a general nature where assumed values may be employed. Application of the technique in planning, designing or analyzing actual installations is only limited by the adequacy with which field information can be obtained.

The time required for solution of ground-water mound problems by resistance network depends on the skill of the operator, the type problem, and the features of the analog itself. The time for setting up and solving flow systems used as examples in this report was 8 to 15 man-hours for the stable-mound problem and 2 to 5 man-hours for each step from one mound position to the next for the moving mound problem.

Approximate equations are developed to predict the rate of rise or fall of the mound center above an original water table. Comparison of these equations with network analyses for two-dimensional rising mounds shows good agreement if the width of the recharge area is less than four times the depth of the originally saturated material.

Application of the horizontal-flow assumption and associated use of the transmissibility coefficient in analytical treatment of ground-water mound behavior can lead to serious errors. It is shown that this assumption can overestimate or underestimate the rate of rise of a mound, depending on whether the original depth of saturated material is relatively small or large, respectively.

PERSONNEL: H. Bouwer

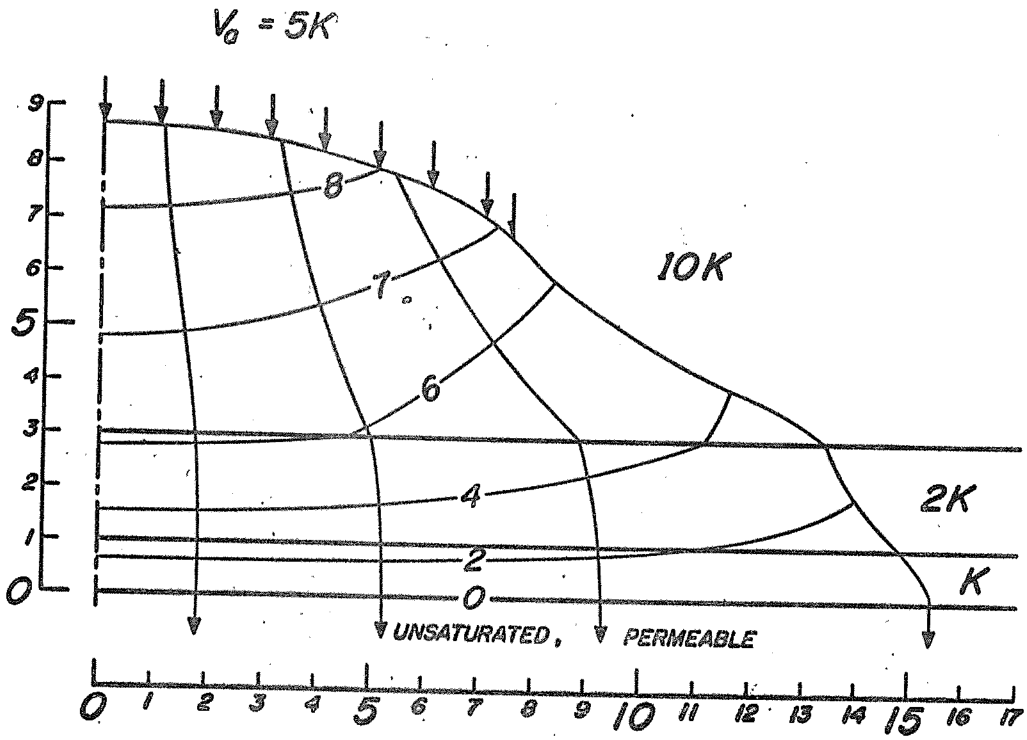


Figure 1. Equilibrium mound above two perching layers.

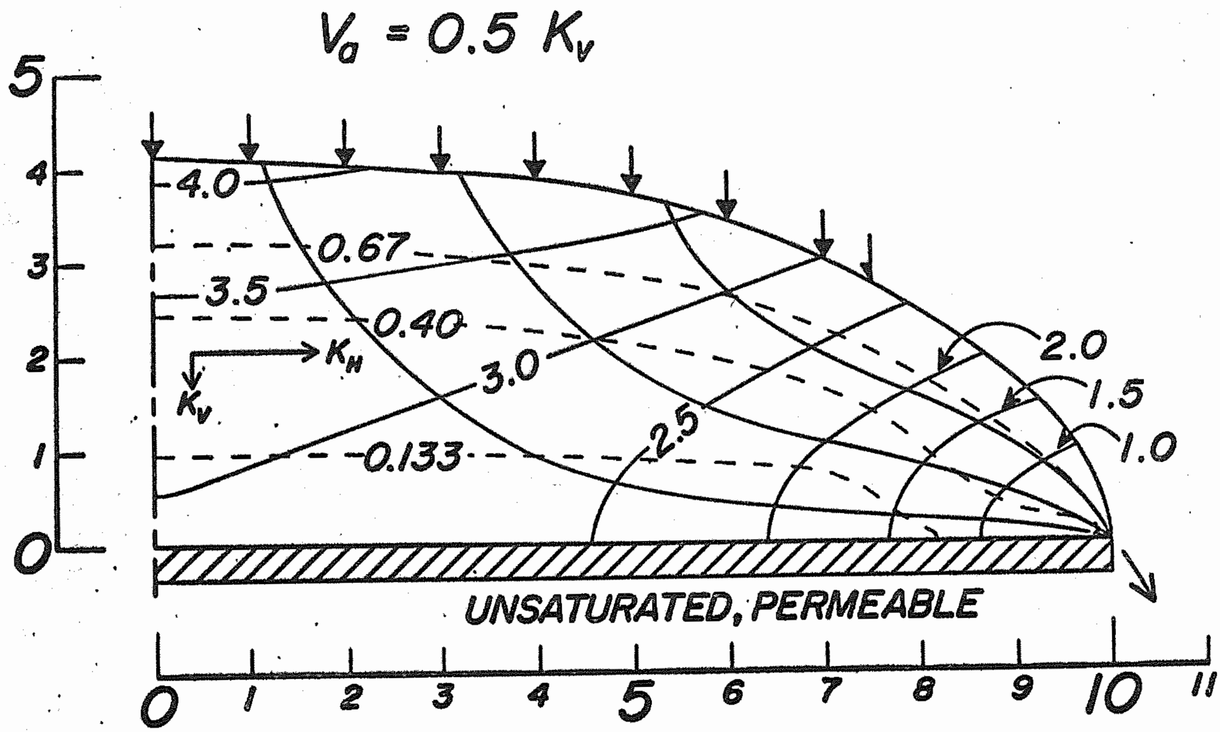


Figure 2. Equilibrium mound in anisotropic soil above discontinuous impermeable zone. Broken lines refer to rising mound positions (see example "d" in section II, "Moving Mounds").

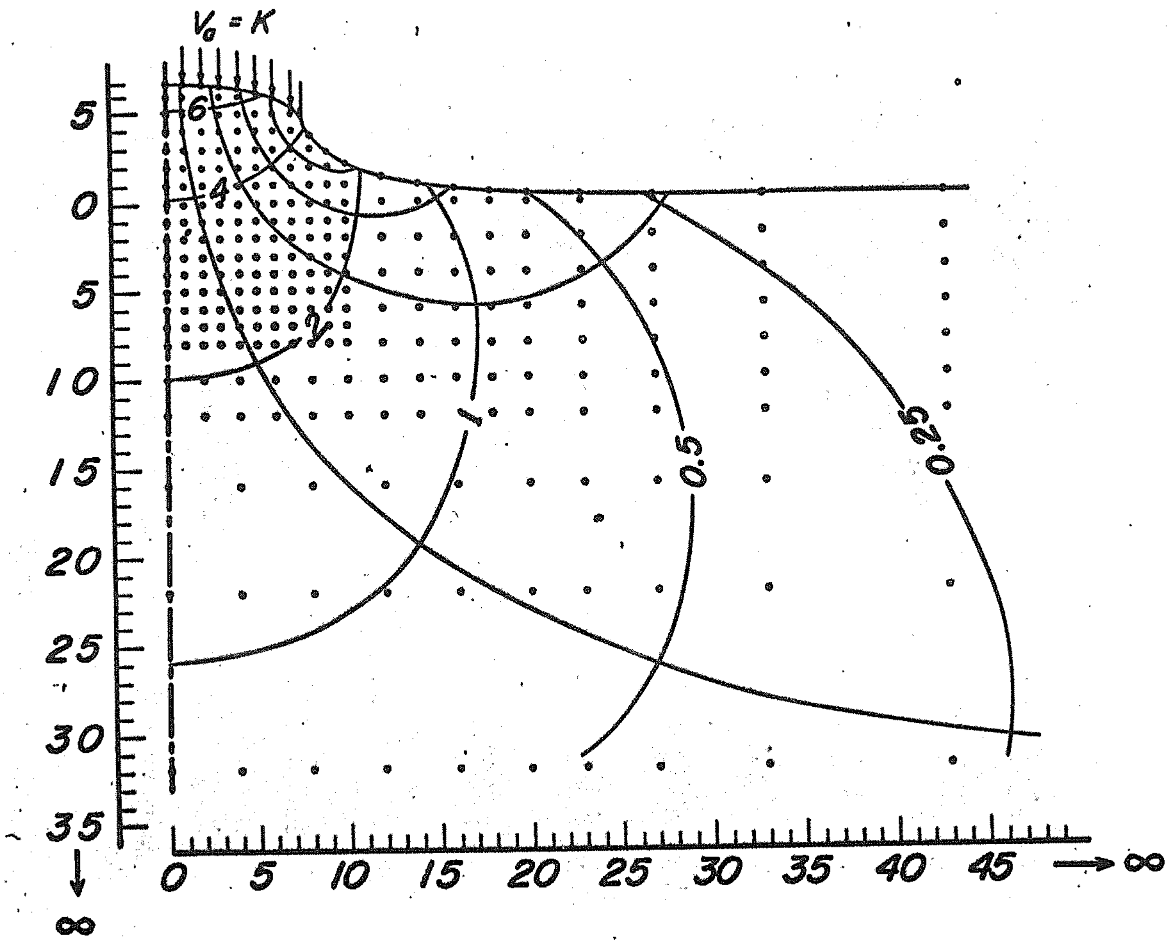


Figure 3. Flow system of rising mound at $\frac{Kt}{fW} = 0.667$, $V_a = K$ and $W/D = 0$.

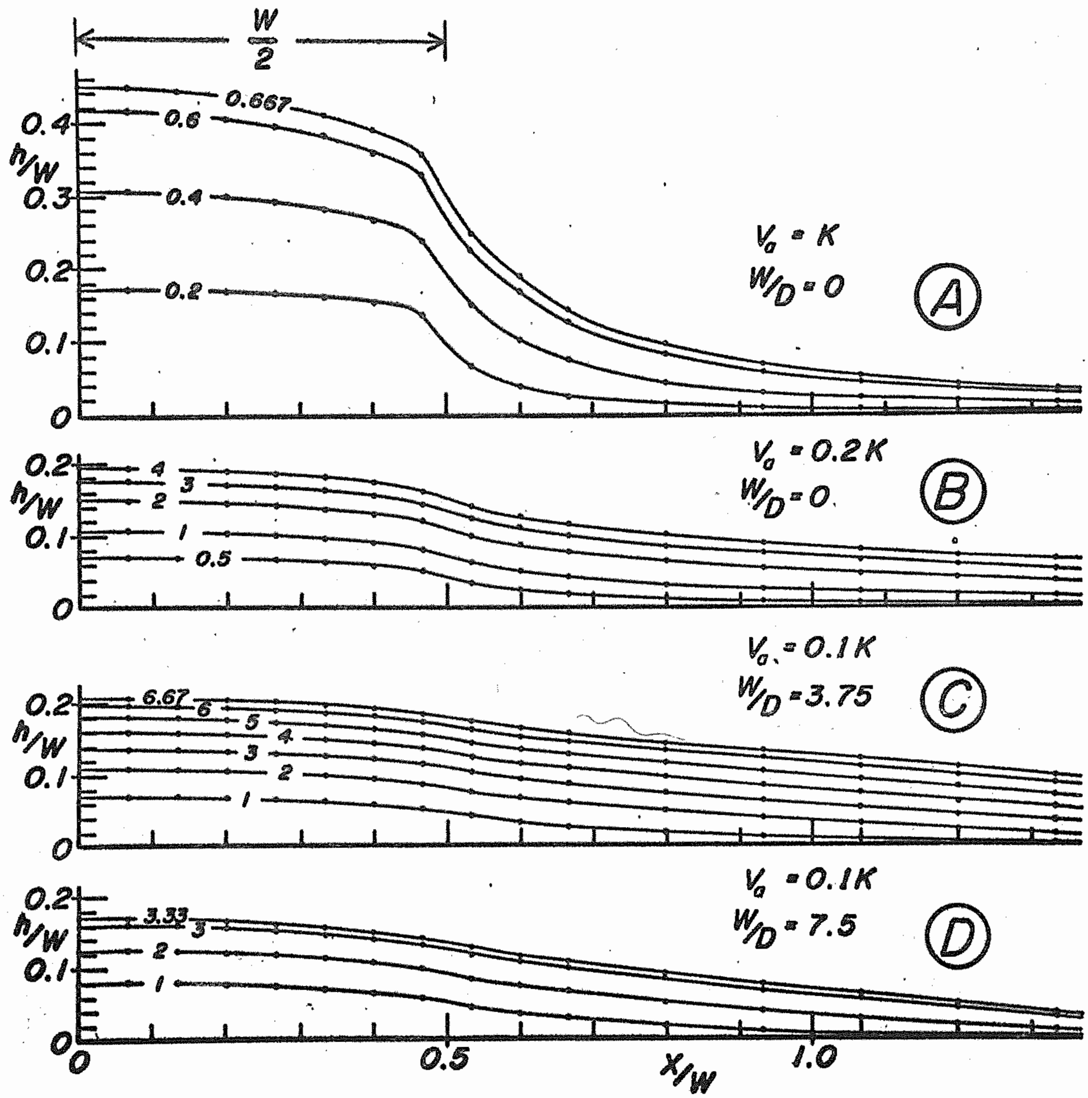


Figure 4. Results of network analyses of rising mounds above an original water table. Numbers on water-table mounds represent values of $\frac{Kt}{fW}$.

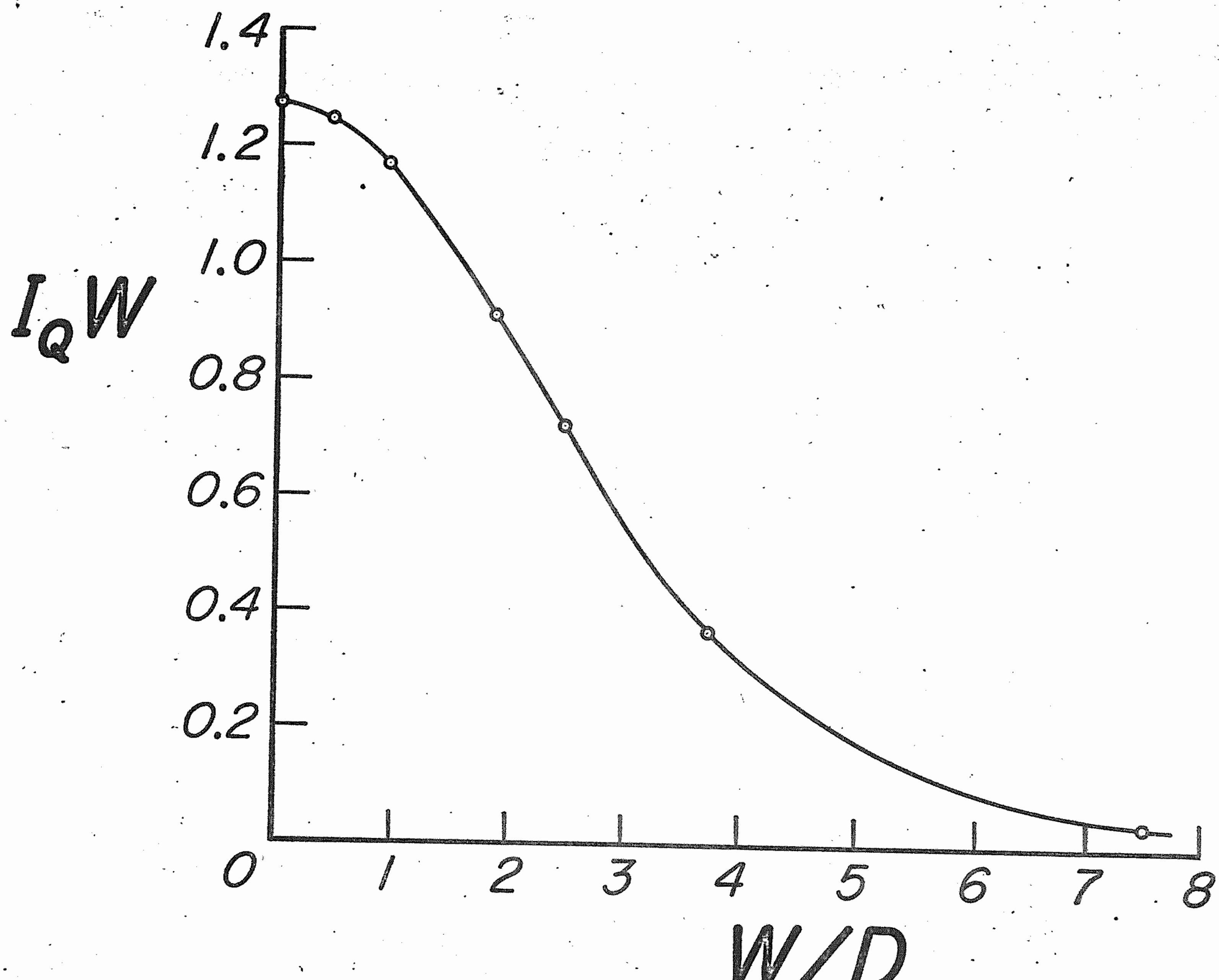


Figure 5. Graph showing $I_Q W$ as a function of W/D for uniform K below the water table.

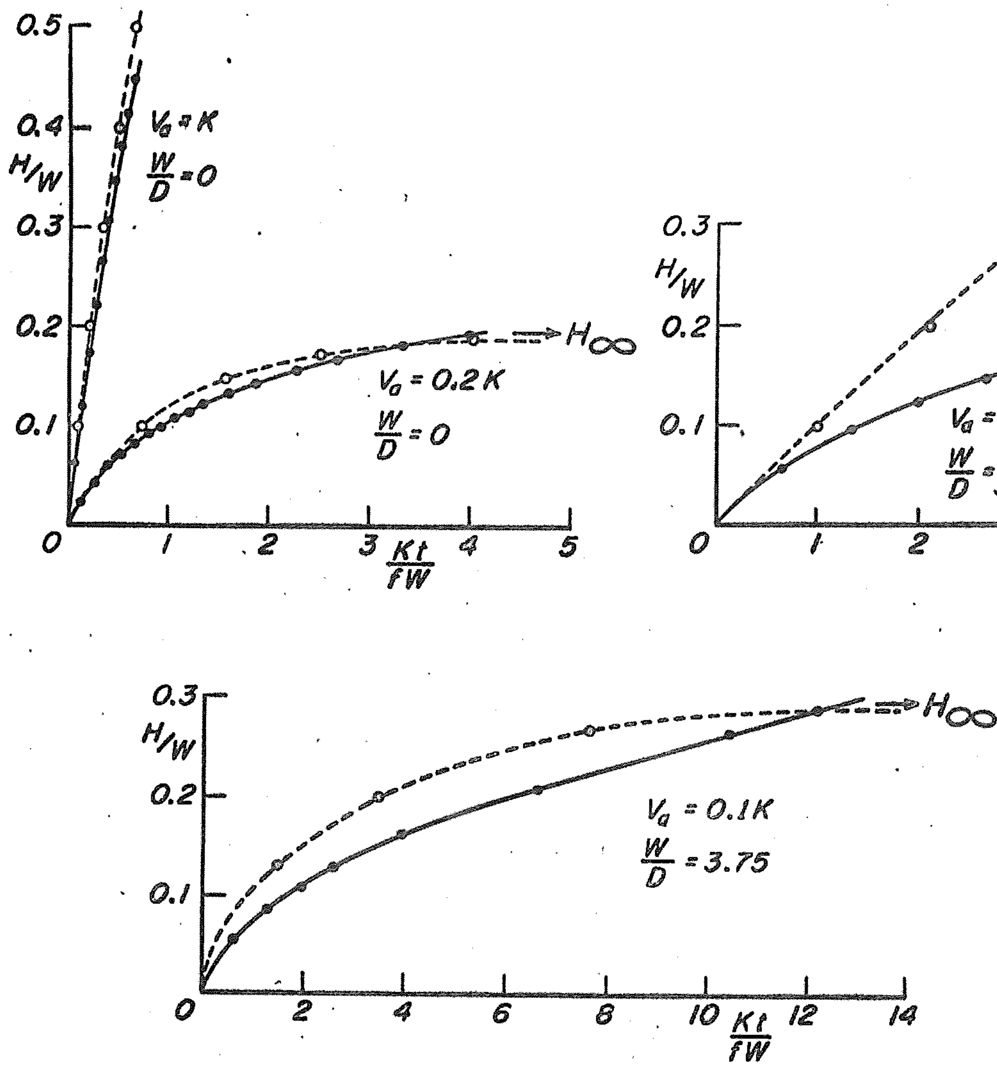


Figure 6. Comparison of rise of mound center calculated with equation (11) (broken lines) with results obtained by resistance network analyses (solid lines).

TITLE: THE USE OF SALTY WELL WATER FOR THE PRE-PLANTING IRRIGATION ON SILTY CLAY SOILS

LINE PROJECT: SWC-4-gG3 CODE: Ariz. WCL-22

INTRODUCTION:

For need of study see Annual Report 1958. The objective of the experiment is to determine the amount of water to apply at the pre-planting irrigation to maintain economic production. The experiment was initiated April 1, 1958.

PROCEDURE:

The experiment is located at the University of Arizona Experiment Farm, Safford Branch, Safford, Arizona. The experiment was conducted on Field "I" borders 1-18.

Plots were plowed in December 1960 and allowed to dry out. On February 28, 1961 the following amounts of pre-planting and leaching water were applied.

1. 8 inches of well water - plots 4, 6, 12, 17
2. 12 inches of well water - plots 3, 8, 10, 16
3. 15 inches of well water - plots 2, 7, 11, 14
4. 18 inches of well water - plots 5, 9, 13, 15

On April 11, 1961 all plots were harrowed and furrows listed out subsequent to planting of cotton. Each plot was planted to four rows of New Mexico 1517 (short staple variety) and four rows of Pima S-2 (long staple variety). An asphalt cap was used on the short staple variety. Soil salt measurements were made on all plots previous to and after the leaching irrigation. A final measurement was made at the harvest date. All water applied in regular irrigations was measured. Only that amount necessary for consumptive use was given. Areas for yield measurements were marked off prior to harvest.

RESULTS AND DISCUSSION:

A good stand of cotton was obtained, though a very cool period followed the planting date. Many parts of the field had marginal moisture at planting time and some plant loss was undoubtedly due to moisture deficiency in addition to Rhizotonia. On June 8, the lower half of the field was disked and planted to sorghum AMAK 410. A good stand of sorghum was obtained.

Early season vigor, plant height, and color differences were observed between leaching treatments. The low leaching treatments, 8 in. and 12 in., were yellower and shorter on both cotton and sorghum. The sorghum heads in the eight-inch leaching treatments were visually smaller.

No yield samples were taken on the sorghum plots because of extensive bird damage. Because of the erratic stand on the eight-inch leaching-cotton-plots, no yield measurements are included in the analysis of variance.

Yield Seed Cotton in Pounds Per Plot (N.M. 1517)

	Reps				
Trts	1	2	3	4	Mean
12"	50.0	44.4	43.3	40.0	44.4
15"	49.2	45.3	48.4	43.2	46.5
18"	47.4	48.9	42.0	45.0	45.8

No. sig.

Yield Seed Cotton Pounds Per Plot (Pima S-2)

Reps.

Trts	1	2	3	4	Mean
12"	40.0	41.1	42.2	51.6	43.7
15"	36.4	46.3	48.2	47.4	44.6
18"	48.6	50.0	48.0	52.0	49.6

No. sig.

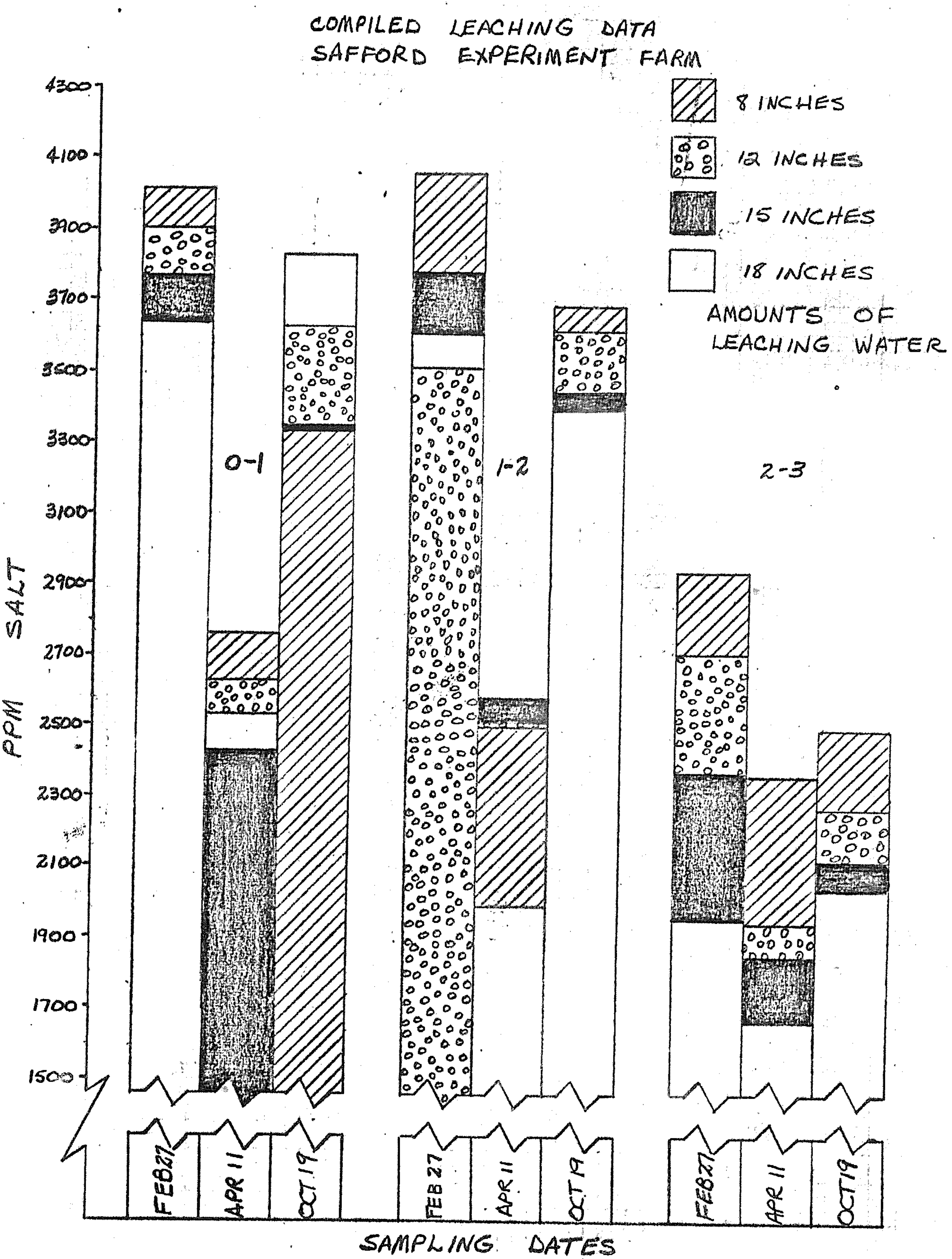
SUMMARY AND CONCLUSIONS:

An eight-inch leaching is significantly inferior to other treatments from a seed germination and vigor standpoint. The after leaching salt samples showed the eight-inch leaching treatment to be about 350 PPM saltier than the fifteen-inch leaching.

An analysis of variance showed no significance in yield, but there was an approximate 10% increase by the heavy leaching treatments.

Inspection of the soil-salt data shows, as in previous years, that twelve to fourteen hundred PPM of salt can be leached out with a single leaching irrigation. The salt differences between treatments after the leaching irrigation were very close in the top two feet, while a larger difference existed in the third foot. If so, it would seem that yield differences could be due at least partly to salt conditions in this profile. All leaching treatments were more efficient in 1961 than in previous years.

PERSONNEL: Leonard J. Erie, Fred O. French, Karl Harris, D. F. McAlister, Fred Turner.


COMPILED LEACHING DATA
SAFFORD EXPERIMENT FARM
8 INCHES
12 INCHES
15 INCHES
18 INCHES
AMOUNTS OF
LEACHING WATER
PPM SALT
4300
4100
3900
3700
3500
3300
3100
2900
2700
2500
2300
2100
1900
1700
1500
0-1
1-2
2-3
FEB 27
APR 11
OCT 19
FEB 27
APR 11
OCT 19
FEB 27
APR 11
OCT 19
SAMPLING DATES

TITLE: DEVELOPMENT AND TESTING OF A MECHANIZED SOIL COLUMN PACKER

LINE PROJECT: SWC 4-gG4 CODE: Ariz.-WCL-12

INTRODUCTION:

The difficulty of packing soils to a uniform bulk density, and the difficulty of obtaining replicate samples for use in physical experiments on soils was reported by Buckingham (1) in 1907.

Since then vibration techniques and the use of hand-operated tremies have partially alleviated this difficulty. The device described here utilizes a motorized tremie and a vibrator block in combination. The device packs columns with soil to a uniform bulk density within the column, reproducibly and rapidly. A 45-centimeter-long column can be packed in 11 minutes with this device.

DESCRIPTION OF DEVICE:

The packer consists of three main parts: a motorized tremie, a vibrator block assembly, and an angle iron frame work uniting the two. Exact dimensions depend upon the length and area of the column to be packed and may vary with individual needs. Construction details, shop drawings, and operating procedures are presented elsewhere (2).

The tremie assembly consists of a stainless steel funnel connected to a 1/2-inch o.d. lucite tube with a lucite spacer fastened to the lower end of the tube. The tremie motor is connected to the tremie by a threaded rod. The tremie assembly is held in a vertical position by a split nut and two aluminum rods, which guide the tremie motor as it ascends. Tremie motors of different speeds can be used to obtain different bulk densities. The split nut provides the means whereby the motor "lifts" itself and the tremie as it rotates.

When initially filling the tremie, unavoidable separation of particles occurs. This causes nonuniform density in the first few centimeters of the column. Also, near the top of the column, extraneous vibrations of the tremie may cause some nonuniformity. For these reasons we use the center 30 cm of a column 45 cm in length for our experiments.

The vibrator block is constructed of jig and fixture aluminum with a vee notch cut in the center to serve as a receptacle for the column. Stainless steel angles are fastened to the four long edges of the block to prevent deformation of the block when vibrating against the adjusting bolts. The adjusting bolts protrude through the frame from four sides and hold the vibrator block vertical and in such a position that the tremie can be freely lowered into the column. The clearance between the bolts and the block is .004 to .005 inch, depending upon the amount of vibration desired. Vibration is produced by a motor with an offset weight on the shaft, mounted on the back of the block. Motors with different amounts of the offset weight can be used to produce different magnitudes of vibration, hence different bulk densities.

The lucite column is clamped in the vee notch of the block by a brass angle, bolted to the block on the top and the bottom. Two lead weights are added to the framework to dampen vibrations of the frame when the block is vibrating.

RESULTS:

Typical results obtained with this device are shown in Table 1. The variation of bulk density among columns was checked by packing five columns for each of three packer settings. Uniformity of bulk density within a column was verified indirectly on two columns by measuring the water content of each 1-cm section of a 30-cm column after equilibrating at -2 mb pressure potential. Similar results have been obtained using other columns of Adelanto loam and other soils.

This project was terminated as of December 31, 1961.

SUMMARY:

A device was designed and constructed to pack columns with soil to a uniform bulk density, rapidly and reproducibly. The device utilizes a motorized tremie and vibration block in combination.

LITERATURE CITED:

(1) Buckingham, E. 1907. Studies on the movement of soil moisture. U.S. Dept. of Agr. Bur. Soils Bul.38:1-61.

(2) Jackson, R. D., Reginato, R. J., and Reeves, W. E. 1962. A mechanized device for packing soil columns. USDA, ARS 41-52.

PERSONNEL: Ray D. Jackson and R. J. Reginato

Table 1.--Typical variation of bulk densities among and within columns packed with Adelanto loam.

Variation Among Columns

Packer setting	Number of columns	Mean bulk density	Coefficient of variation
		gm cm^{-3}	
1	5	1.429	.003
2	5	1.474	.002
3	5	1.547	.002

Variation Within Columns

Column	Number of sections	Mean bulk density	Coefficient of variation
		gm cm^{-3}	
1	30	1.453	.004
2	30	1.519	.004

TITLE: MEASUREMENT AND CALCULATION OF UNSATURATED CONDUCTIVITY AND SOIL-WATER DIFFUSIVITY

LINE PROJECT: SWC 4-gG4 CODE: Ariz.-WCL-13

INTRODUCTION:

This project was undertaken to obtain quantitative measurements of soil-water diffusivities for various soil conditions and to calculate the unsaturated conductivity, and hence the diffusivity from water-retention characteristics and to compare the calculated and measured values. Basic knowledge of unsaturated flow of soil water is fundamental to a better understanding of the processes of infiltration, transmission, and storage of water in soil. Equations used to describe unsaturated flow conditions such as infiltration and evaporation contain a transmission factor, either the unsaturated conductivity or the soil-water diffusivity. Both of these factors are dependent on the water content of the soil. In addition both factors are influenced by soil texture, packing, temperature, and numerous other conditions of the soil.

Although the theory of the flow of water in unsaturated soils is well advanced (3), few quantitative experiments have been reported. Only limited success has been achieved in obtaining a rapid, reproducible, reliable method for determining the unsaturated conductivity or the soil-water diffusivity. Inhomogeneous packing is a reason frequently cited as a cause of poor reproducibility of soil-water diffusivity measurements. The recent development of a mechanized soil column packer (2) offers promise of alleviating this difficulty. Columns packed with the mechanized packer yield water distribution curves from which precise soil-water diffusivity measurements can be made.

METHOD:

Quantitative measurements of soil-water diffusivity are made by allowing water to enter one end of a horizontal soil column at a slight negative pressure for a given period of time. At the end of the time period, the water is disconnected and the column rapidly sectioned into 1-cm sections, and the gravimetric water content is determined for each section. The gravimetric water content is converted to volumetric water content by multiplying by the dry bulk density. The distance from the source is then plotted as a function of volumetric water content and the soil-water diffusivity is calculated for a particular water content by evaluating the slope of the x vs θ curve and the area under the curve for that particular water content. The relationship between the soil-water diffusivity, the elapsed time, the slope of the line, and the area under the curve is [Barrer (1)]

$$D_\theta = -\frac{1}{2t}\frac{dx}{d\theta}\int_{\theta_1}^{\theta_2} x\,d\theta \quad ,$$

where D_θ is the soil-water diffusivity ($cm^2\ min^{-1}$) at the water content θ, t is the time during which the experiment was carried out (min), x the distance from the source (cm), θ the volumetric water content ($cm^3\ cm^{-3}$). At water contents near saturation, the slope of the x vs θ line approaches infinity and at water contents near the initial water content of the sample, the slope of the line is very nearly zero. Because of this, quantitative diffusivity values can only be obtained within an intermediate water content range.

RESULTS:

Soil-water diffusivity measurements were made on three soils: Adelanto loam, Fort Collins loam, and Pachappa loam, The Adelanto loam was packed to three densities, each in duplicate. The Fort Collins loam was packed to two densities, each in duplicate, and the Pachappa loam was packed to two densities, each in duplicate. During the course of each run, measurements were made on the rate of advance of the wetting front and the quantity of water absorbed by the soil as a function of time. At the conclusion of each run the time was noted, the column was rapidly sectioned into 1-cm sections and the gravimetric water content determined. The volumetric water content was calculated and plotted as a function of the distance from the source. Soil-water diffusivity measurements were made at each density. The results are shown in Figures 1, 2, and 3. Each point in the figure is the average of two measurements made on separate columns packed to the same density, but with water allowed to imbibe for different time intervals.

Figure 1 shows that quantitative diffusivity measurements for Adelanto loam can only be made in water contents of about 28 to 37 percent, when the initial water content is

3.6 percent and the saturated water content is 40 percent. Within this rather limited range, however, differences in soil-water diffusivity can be observed for columns packed to different densities. The same holds for Figures 2 and 3 which give diffusivity data for Fort Collins loam and Pachappa loam. In all cases the columns packed to the lightest density exhibit the highest diffusivity. At water contents nearer saturation, the lines for the diffusivity at each density tend to coalesce and in some cases cross over. This is due in part to the fact that soils packed to heavier densities will have a lower saturated water content and the slope of the x vs θ curve will become larger at a lower water content.

Although diffusivities at water contents near the initial water content could not be measured by the present method, some indication of the differences that exist can be inferred from the rate of advance of the wet front for different densities (Figure 4). The rate of advance of the wet front decreases with increasing density which indicates that the diffusivity associated with the initial water content may be affected more by density than the diffusivities at the higher water content.

Figure 5 shows the mean weighted diffusivity calculated from inflow measurements. The mean weighted diffusivity is obtained from the slope of quantity of intake per unit area versus the square root of time curve. As one would expect, the mean weighted diffusivity decreases with increasing density.

Figure 6 shows a water content distribution for Adelanto loam packed to a density of 1.446 g cm^{-3}. The curve indicated by x was obtained after time of 258 minutes had elapsed from initiation of the experiment. The curve indicated by dots was obtained 546 minutes after water was first introduced in the column. The curve indicated by circles was obtained after wetting a 30-cm column and allowing it to remain in contact with the water source for three days. This figure shows how the water content at the source during an inflow experiment may change with time. This change is probably caused by dissolving of entrapped air. One of the mathematical assumptions in the derivation of the diffusion equation as applied to soil water is that the water content at the source remains constant with time. Thus, in the strict sense, diffusion theory will not describe the flow of water into air-dry Adelanto loam. This phenomena was also noticed in the Fort Collins loam and the Pachappa loam, but to a lesser extent.

In Figure 6 the line indicated by circles shows the degree of uniformity of the packing. Throughout the 30-cm column the range of water content distribution was less than 1 percent by volume.

SUMMARY

Measurements of the soil-water diffusivity for three soils at several densities show that soil-water diffusivity decreases with increasing density. This difference is more striking at the lower water contents and tends to diminish to zero at the water

contents near saturation. The rate of advance of the wetting front and the rate of intake of water versus the square root of time also decrease with increasing density. On Adelanto loam the water content at saturation was shown to increase with time probably due to dissolving of entrapped air into the water. This dependency upon time of the water content of saturation indicates that the diffusion analysis as applied to soil water may not hold exactly for finer textured soils.

REFERENCES

(1) Barrer, R. M. Diffusion in and through solids, p. 48. Cambridge Univ. Press, Cambridge. 1951.

(2) Jackson, R. D., Reginato, R. J., and Reeves, W. E. A mechanized device for packing soil columns. USDA, ARS 41-52, 1962.

(3) Phillip, J. R. The physical principles of soil water movement during the irrigation cycle. Third International Congress on Irrigation and Drainage Proceedings 8.125-8.154. 1957.

PERSONNEL: Ray D. Jackson

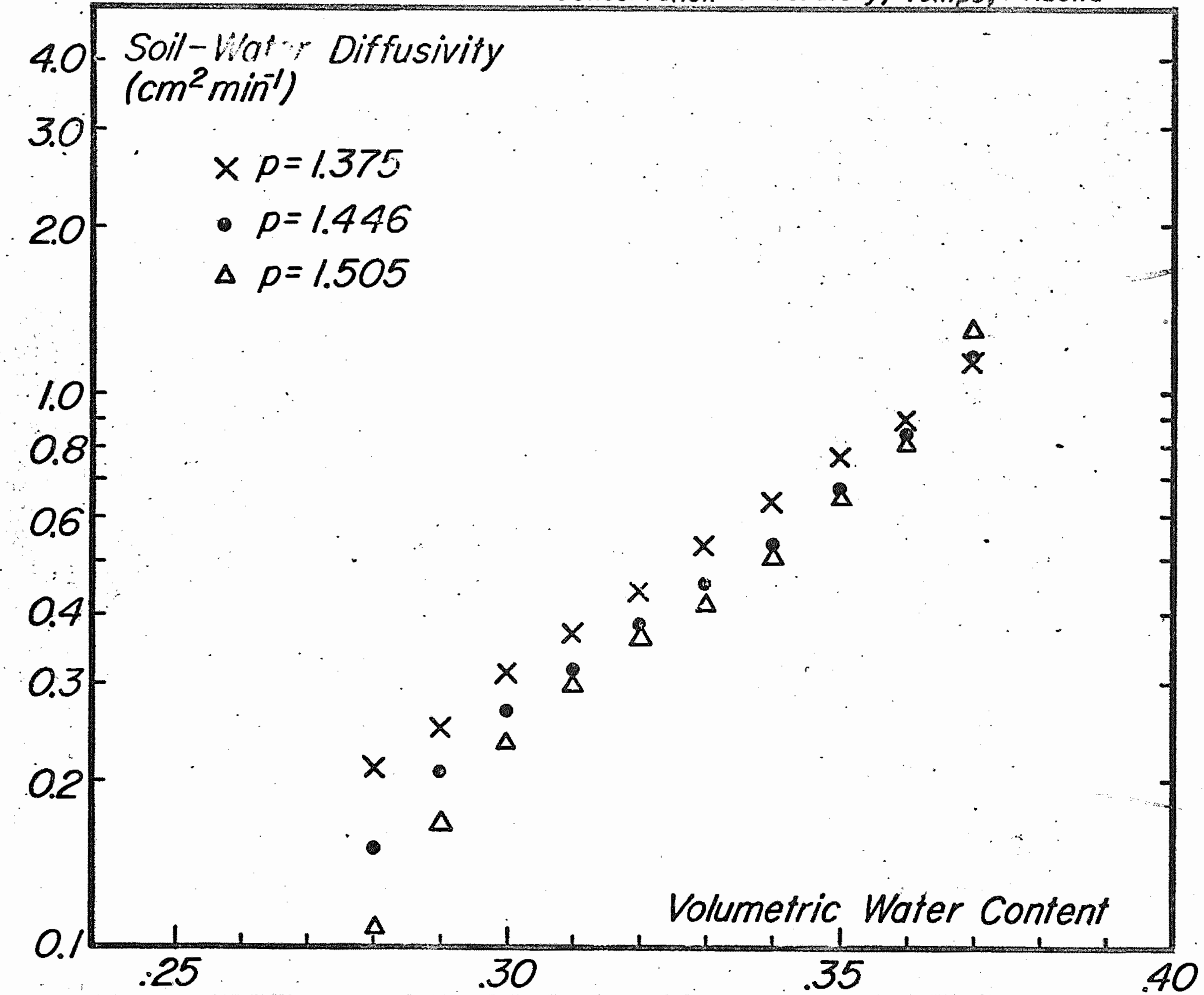


Figure 1. Measure of soil-water diffusivity for Adelanto loam.

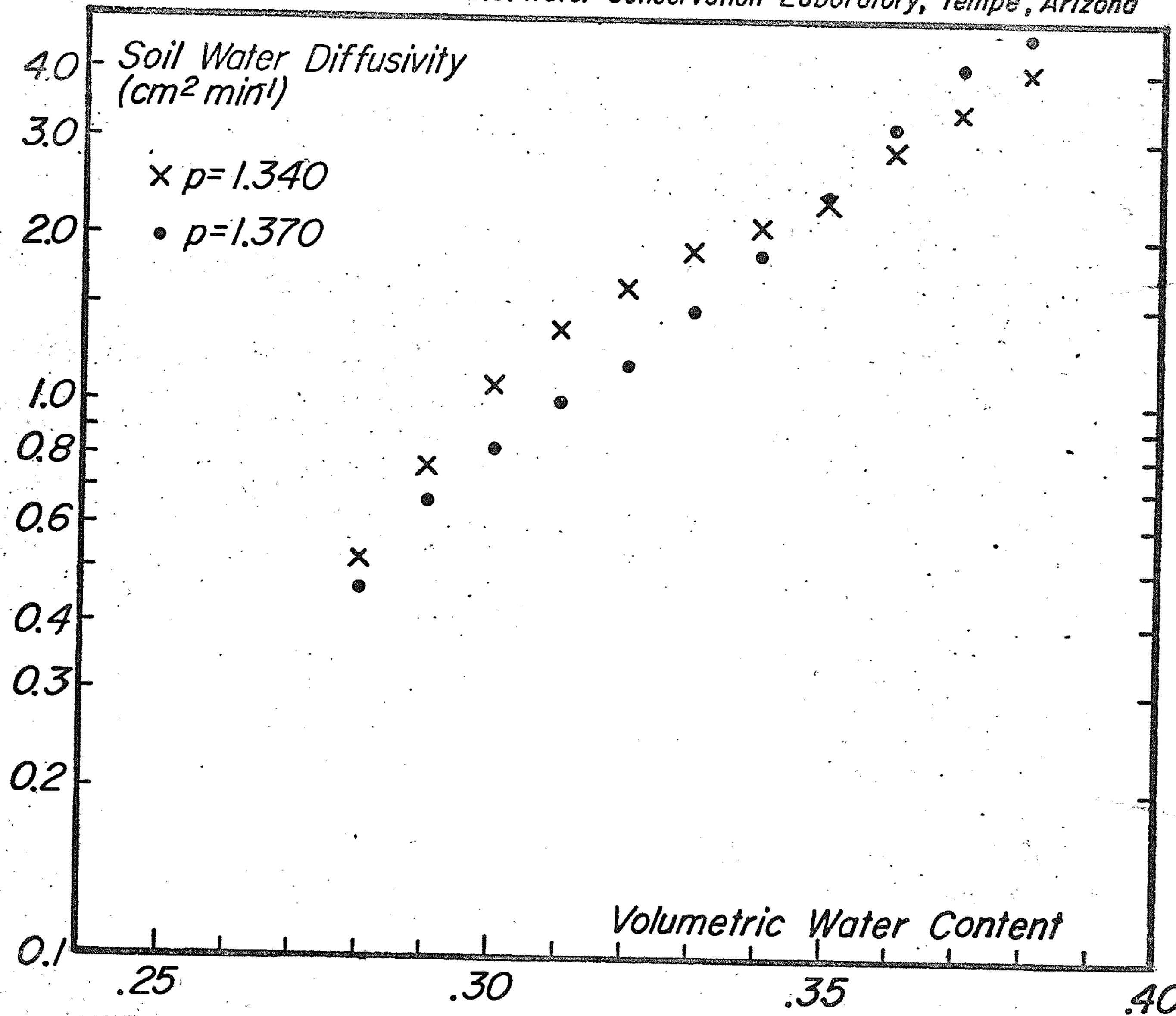


Figure 2. Measured soil-water diffusivity for Fort Collins loam.

U.S. Water Conservation Laboratory, Tempe, Arizona

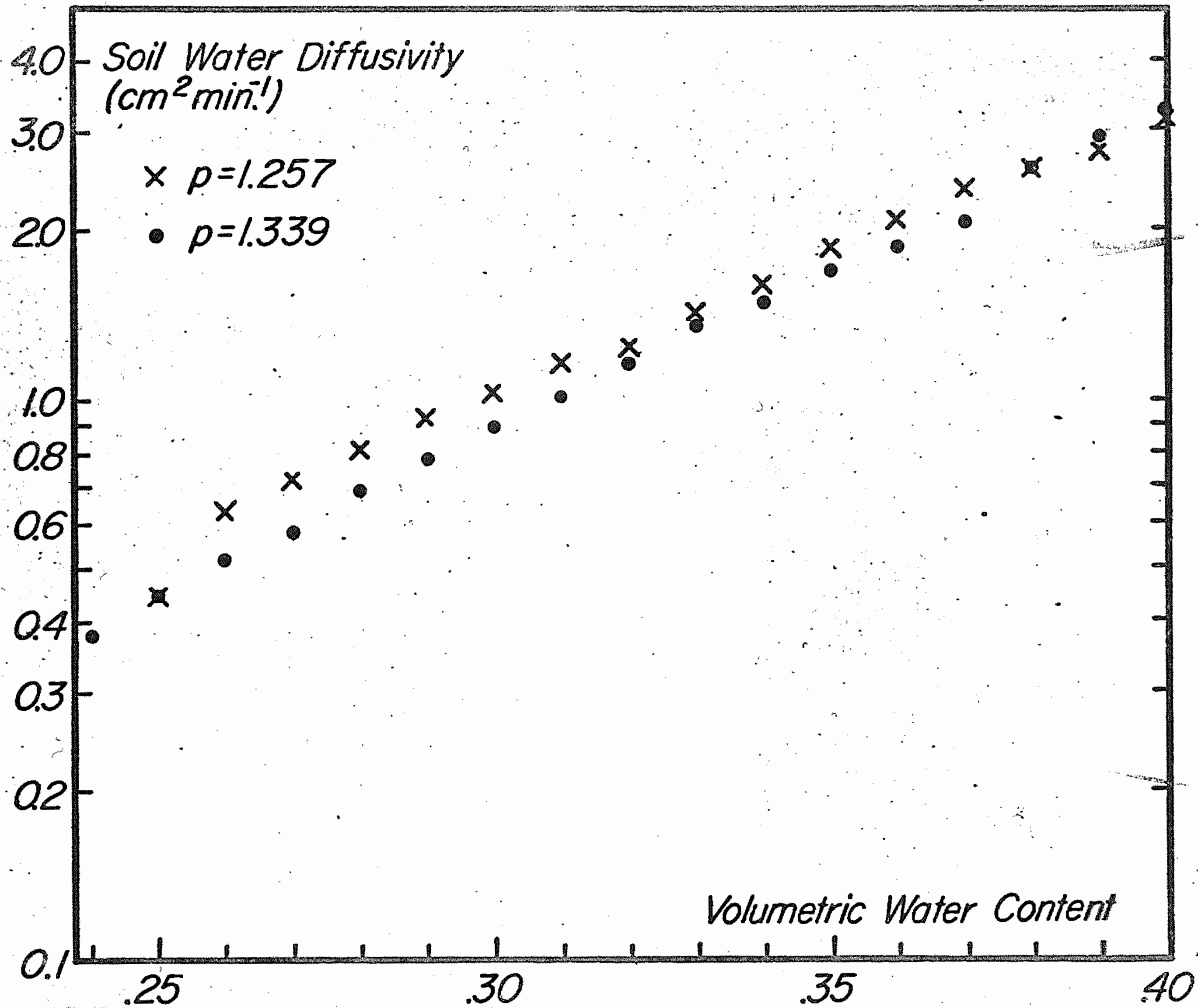


Figure 3. Measured soil-water diffusivity for Pachappa loam.

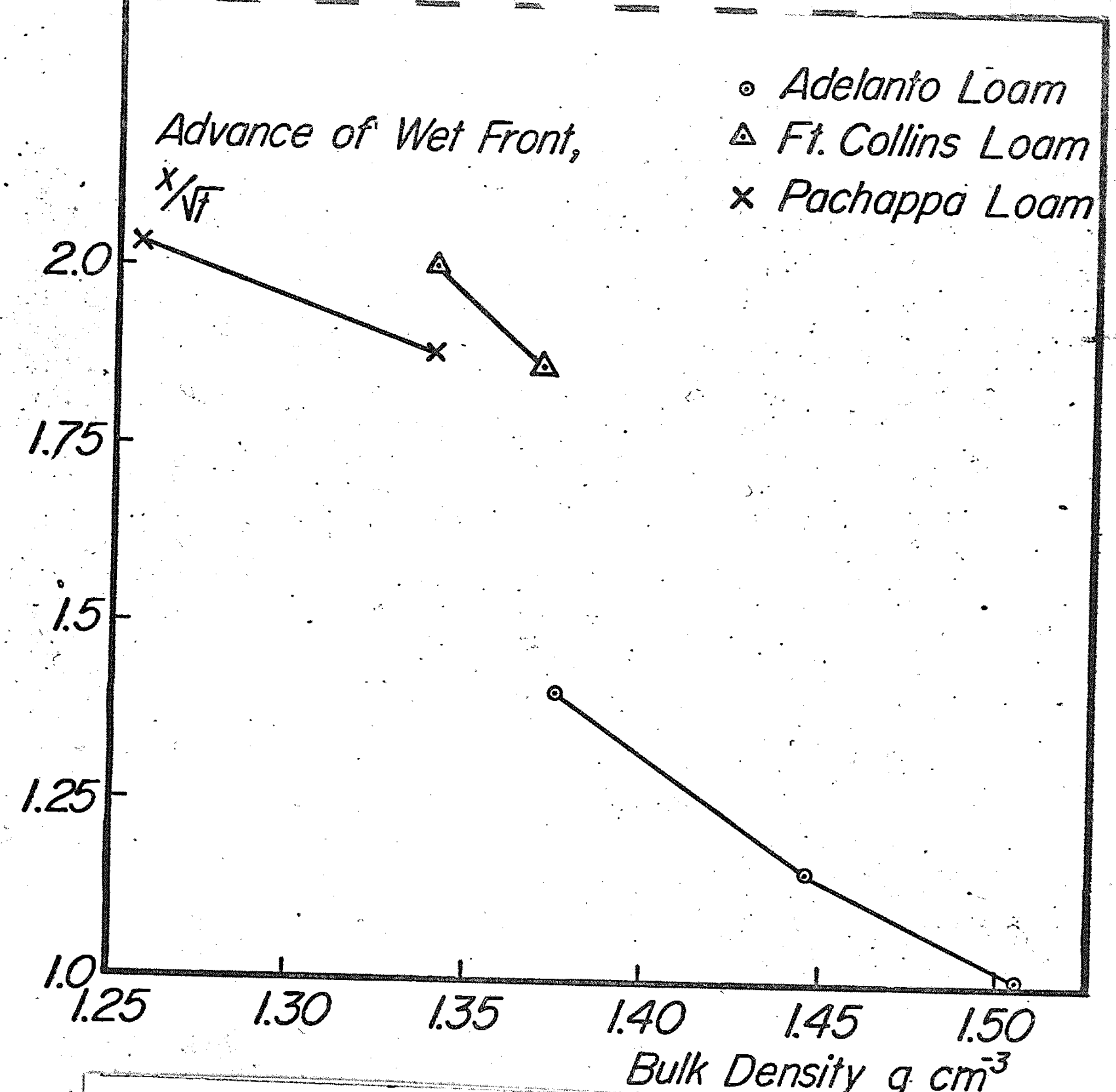


Figure 4. Advance of wet front versus bulk density for three soils.

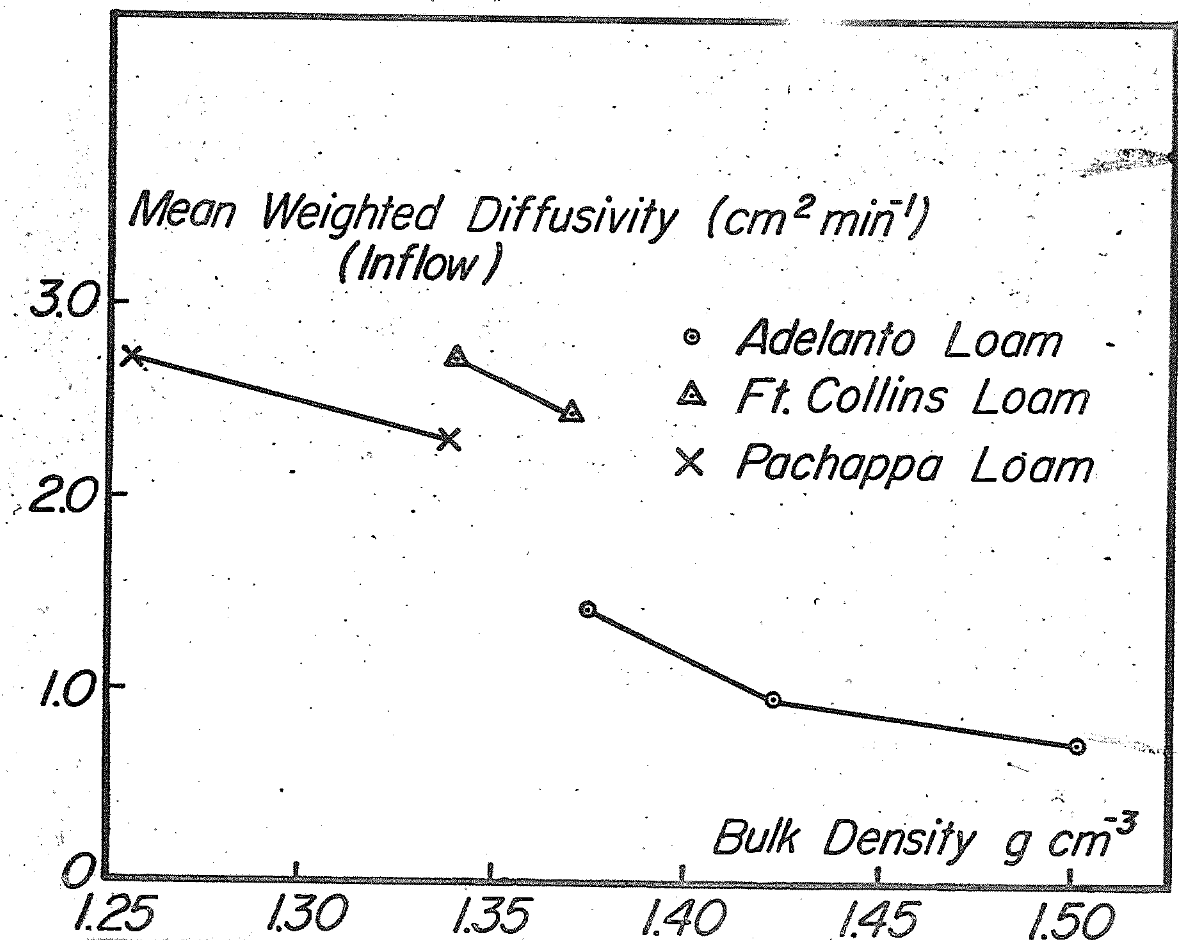


Figure 5. Mean weighted diffusivity versus bulk density for three soils.

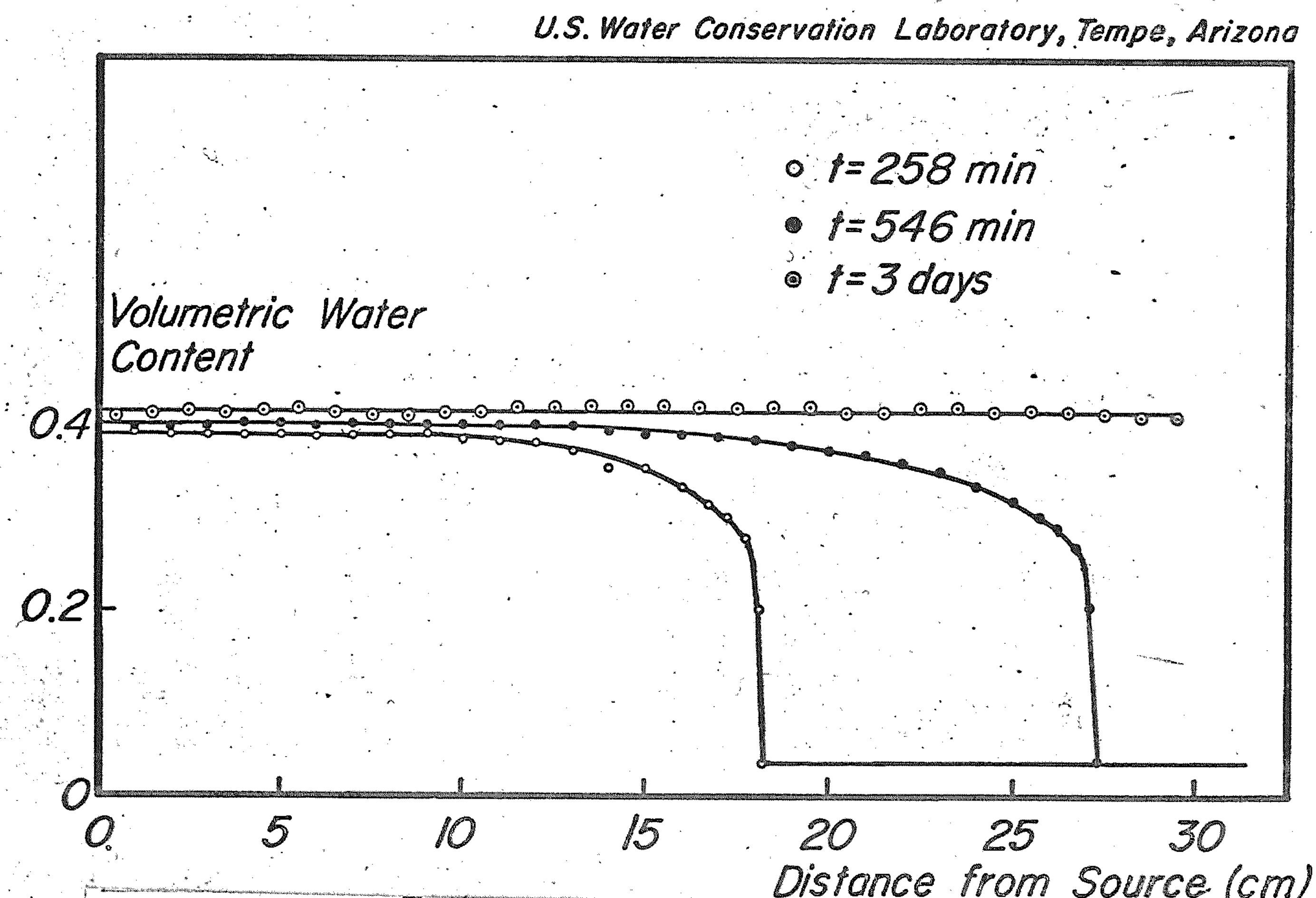


Figure 6. Water content versus distance from source for Adelanto loam, bulk density 1.446 g cm^{-3}.

TITLE: DYNAMIC SIMILARITY IN ELBOW FLOW METERS

LINE PROJECT: SWC 4-gG 5 CODE NO.: Ariz.-WCL-2

INTRODUCTION:

See Annual Report for 1960.

PROCEDURE:

Experimental procedures were the same as for 1960 except for minor variations noted in the discussion of results. An Exactel Instrument Company, Model I-560 IN-D, servomanometer, which provides digital readout accurate to 0.06 inch of water over a range of 60 inches of mercury, was used to measure pressure distribution within a test elbow. Discharge equations for all tests were calculated by the method of least squares and checked by three different staff members. All tests were made on cast, flanged, long and short radius, 3-inch ID commercial elbows.

RESULTS AND DISCUSSION:

Tests were made during 1961 to determine the influence on calibration of an elbow meter by disturbance of a 180 degree bend, rotation of a gate valve, pressure tap size and pressure tap location. Calibration of 10 different short radius and 8 different long radius 3-inch diameter elbows was conducted under standard conditions. Standard flow conditions consisted of 28 and 12 diameters of straight pipe upstream and downstream respectively, with flow controlled by a gate valve 12 diameters downstream. A wide-open gate valve was 28 diameters upstream.

180 degree bend: Bends induce a double spiral flow and cause errors in elbow meter flow measurements if installed too near the elbow meter. Two 3-inch 90 degree short radius elbows were installed to form a horizontal 180 degree bend at 4, 8, 12, 16, 20, and 28 diameters upstream from a horizontal elbow meter. A gate valve 12 diameters downstream from the elbow meter was used to regulate the flow. Table 1 gives the discharge equations and per cent deviations in flow rate for each 180 degree bend installation. The bend induced higher pressure differentials when installed too near the elbow. The maximum deviation was -0.045 cfs at 1.000 cfs and occurred when the bend was nearest the elbow meter. Twenty-eight diameters of straight pipe reduced the deviation to -0.011 cfs at 1.000 cfs. The standard equation used for comparison was obtained with the same elbow meter used in this test when the 180 degree bend was replaced with a gate valve 28 diameters upstream from the meter.

Gate valve: Partially opened gate valves may cause serious errors in elbow meter measurements because of the non-concentric jet from the partially opened gate. A 3-inch gate valve was installed at various distances upstream from a horizontally mounted elbow meter, with 40 diameters of straight pipe downstream, and was used to control the flow. The valve was rotated about the pipe axis so that the non-concentric jet was directed alternately toward the inside, bottom and outside of the elbow meter bend. Table 2 presents the discharge equations compared to the equation obtained with the same meter in a standard installation. Twenty diameters of straight pipe reduced the deviation to less than 2 per cent, even at low flow rates with a slightly opened gate, if the jet was not directed toward the inside or outside of the elbow bend. Deviation exceeding 2 per cent occurred at low flows with 28 diameters of straight pipe if the jet was directed toward either the inside or the outside of the bend.

Pressure tap size: The standard pressure tap diameter was 0.120 inch. The diameter was increased in approximately 0.020 inch increments to 0.250 inch to determine any effect on calibration with the results shown in Table 3. Maximum deviation was less than 2 per cent.

Pressure tap location: The accuracy required in the location of pressure taps in the elbow meter was investigated by installing 18 taps as shown in Figure 1 and measuring static pressure for several flow rates. Pressure distribution for two flow rates is shown in Figure 2. The data indicate that tap location is not critical.

Short radius elbow variation: Pairs of flanged short radius, 3-inch diameter, cast elbows were obtained from five different manufacturers and calibrated under standard conditions. Following the first calibration each elbow was reversed and a second calibration made. Elbows 5 and 6 had a different radius of curvature and the discharge equations for these elbows is somewhat different than the others, as shown in Table 4. Inside diameters of the other elbows varied from 2.75 to 3.06 inches and roughness patters were different. Despite this fact, except for the reversed flow reading on elbow 3, the maximum deviation from the average equation at 1.00 cfs was less than 2 per cent for all other elbows. The average equation was $Q = 0.326H^{0.501}$.

Long radius elbow variation: Pairs of flanges long radius, 3-inch diameter, cast elbows were obtained from four different manufacturers and calibrated under standard conditions. Following the first calibration each elbow was reversed and a second calibration made. Results are presented in Table 5. The average equation was $Q = 0.408H^{0.498}$. Except for elbows 13 and 16 the maximum deviation at 1.00 cfs was less than 2 per cent.

SUMMARY AND CONCLUSIONS:

The influence of various factors on the flow rate-pressure differential relationships was investigated, including the effect of a 180 degree bend, gate valve position, pressure tap size and pressure tap location. The influence of the 180 degree bend was reduced to about 1 per cent deviation at 1.00 cfs and about 4 per cent at 0.10 cfs by 28 diameters of straight pipe upstream from the elbow meter. Deviations caused by a gate valve were reduced to less than 1 per cent at 1.00 cfs by 20 diameters of straight pipe if the jet from the partially opened gate was not diverted toward the inside or the outside of the elbow meter bend. Increasing pressure tap diameter from 0.125 to 0.250 inch caused deviations of less than 2 per cent. Pressure tap location was not extremely critical and no appreciable error should be introduced if the taps are located within 0.50 inch of the ideal location.

Long and short radius elbows made by different manufacturers were calibrated under standard conditions and recalibrated in reversed positions. Deviations from the average flow equation for each type of elbow were less than 2 per cent at 1.00 cfs for most of the elbows.

The test results indicate that standard discharge equations can be used for most 3-inch diameter, cast, flanged commercial elbows with errors less than 2 per cent at 1.00 cfs and less than 5 per cent at 0.10 cfs. Deviation due to all flow disturbances tested, including a 180 degree bend, can be reduced below these percentages by 28 diameters of straight pipe upstream from the meters. Size of taps and location of taps was not critical. The elbows do not have to be calibrated in place and can be removed and replaced with no serious effect.

PERSONNEL: L. E. Myers, K. J. Brust.

Table 1. Discharge equations and per cent deviations in flow rate with 180 degree bend at various diameters upstream from an elbow meter.

Diameters	Discharge Equation	Per cent Deviation in Flow Rate at	
		0.100 cfs	1.000 cfs
4	$Q = 0.319H^{0.498}$	-1.4	-4.5
8	$0.328H^{0.495}$	+2.1	-2.5
12	$0.328H^{0.501}$	+0.6	-1.2
16	$0.332H^{0.490}$	+4.5	-2.4
20	$0.333H^{0.492}$	+4.4	-1.6
28	$0.332H^{0.496}$	+3.4	-1.1
28 standard	$0.329H^{0.505}$	--	--

Table 2. Discharge equations and per cent deviations in flow rate with flow rate regulated by a gate valve at various diameters upstream from an elbow meter.

Diameters	Jet Toward	Discharge Equation	Per Cent Deviation in Flow Rate at 0.100 cfs	Per Cent Deviation in Flow Rate at 1.000 cfs
4	Bottom	$Q = 0.311H^{0.513}$	-5.4	-3.3
8	"	$0.321H^{0.508}$	-1.2	-1.2
12	"	$0.318H^{0.516}$	-4.0	-0.4
16	"	$0.324H^{0.501}$	+1.3	-1.8
20	"	$0.326H^{0.507}$	+0.5	+0.1
28	"	$0.322H^{0.511}$	-1.4	-0.5
28 standard		$0.325H^{0.508}$	--	--
4	Inside Bend	$0.318H^{0.497}$	+0.4	-4.5
28	"	$0.330H^{0.499}$	+3.7	-0.1
4	Outside Bend	$0.317H^{0.511}$	-3.1	-1.8
28	"	$0.328H^{0.500}$	+2.8	-0.9

Table 3. Discharge equations and per cent deviations in flow rate for various pressure tap diameters.

Tap Size		Discharge Equation	Per cent Deviation in Flow Rate at	
			0.100 cfs	1.000 cfs
Standard	0.120 inch	$Q = 0.326H^{0.501}$	--	--
	0.159 "	$0.326H^{0.497}$	+0.9	-0.9
	0.180 "	$0.325H^{0.499}$	+0.2	-0.7
	0.194 "	$0.325H^{0.497}$	+0.6	-1.2
	0.206 "	$0.323H^{0.501}$	-0.9	-0.9
	0.228 "	$0.325H^{0.497}$	+0.6	-1.2
	0.250 "	$0.323H^{0.498}$	-0.2	-1.6

Table 4. Discharge equations and per cent deviation in flow rate for commercial 3-inch, cast iron, flanged, short radius, 90 degree elbows under standard conditions.

Elbow Number Short Radius	Discharge Equation	Per cent Deviation in Flow Rate at 0.100 cfs	Per cent Deviation in Flow Rate at 1.000 cfs
1	$Q = 0.325H^{0.508}$	-1.9	+1.3
Flow Reversed	$0.325H^{0.503}$	-0.8	+0.1
2	$0.329H^{0.505}$	0.0	+1.8
" "	$0.328H^{0.505}$	0.0	+1.5
3	$0.321H^{0.500}$	-1.3	-1.8
" "	$0.320H^{0.497}$	-0.9	-2.7
4	$0.326H^{0.501}$	--	--
" "	$0.320H^{0.500}$	-1.6	-2.1
5	$0.348H^{0.499}$	+7.2	+6.3
" "	$0.347H^{0.494}$	+8.2	+4.8
6	$0.339H^{0.497}$	+5.0	+3.1
" "	$0.338H^{0.503}$	+3.2	+4.2
7	$0.330H^{0.490}$	+3.8	-1.2
" "	$0.333H^{0.495}$	+3.6	+0.8
8	$0.329H^{0.493}$	+2.8	-0.9
" "	$0.328H^{0.491}$	+3.0	-1.6
9	$0.323H^{0.499}$	--	-1.4
" "	$0.328H^{0.501}$	+0.6	+0.6
10	$0.330H^{0.497}$	+2.2	+0.3
" "	$0.326H^{0.496}$	+1.2	-1.1

Table 5. Discharge equations and per cent deviation in flow rate for commercial 3-inch, cast iron, flanged, long radius, 90 degree elbows under standard conditions.

Elbow Number Long Radius	Discharge Equation	Per cent Deviation in Flow Rate at 0.100 cfs	Per cent Deviation in Flow Rate at 1.000 cfs
11	$Q = 0.411H^{0.497}$	+1.0	+0.6
Flow Reversed	$0.409H^{0.494}$	+1.4	-0.5
12	$0.408H^{0.498}$	--	--
" "	$0.403H^{0.496}$	-0.7	-1.6
13	$0.421H^{0.490}$	+5.5	+1.7
" "	$0.422H^{0.493}$	+4.9	+2.5
14	$0.412H^{0.502}$	-0.1	+1.7
" "	$0.410H^{0.500}$	-0.1	+0.9
15	$0.403H^{0.502}$	-2.3	-0.5
" "	$0.400H^{0.502}$	-3.0	-1.3
16	$0.401H^{0.495}$	-0.9	-2.2
" "	$0.401H^{0.495}$	-0.9	-2.2
17	$0.406H^{0.498}$	-0.5	-0.5
" "	$0.410H^{0.500}$	-0.1	+0.9
18	$0.417H^{0.494}$	+3.4	+1.5
" "	$0.405H^{0.502}$	-1.8	0.0

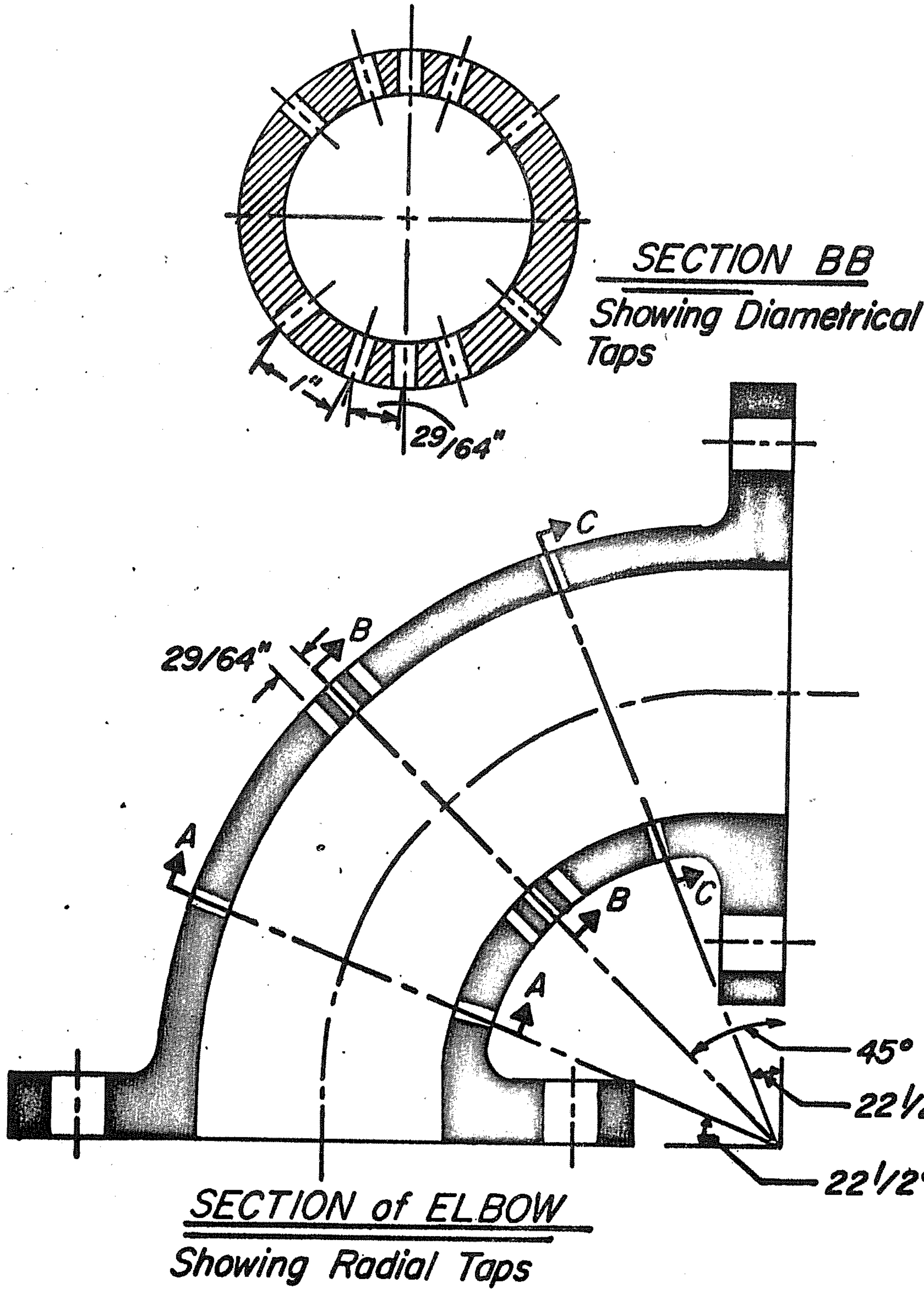
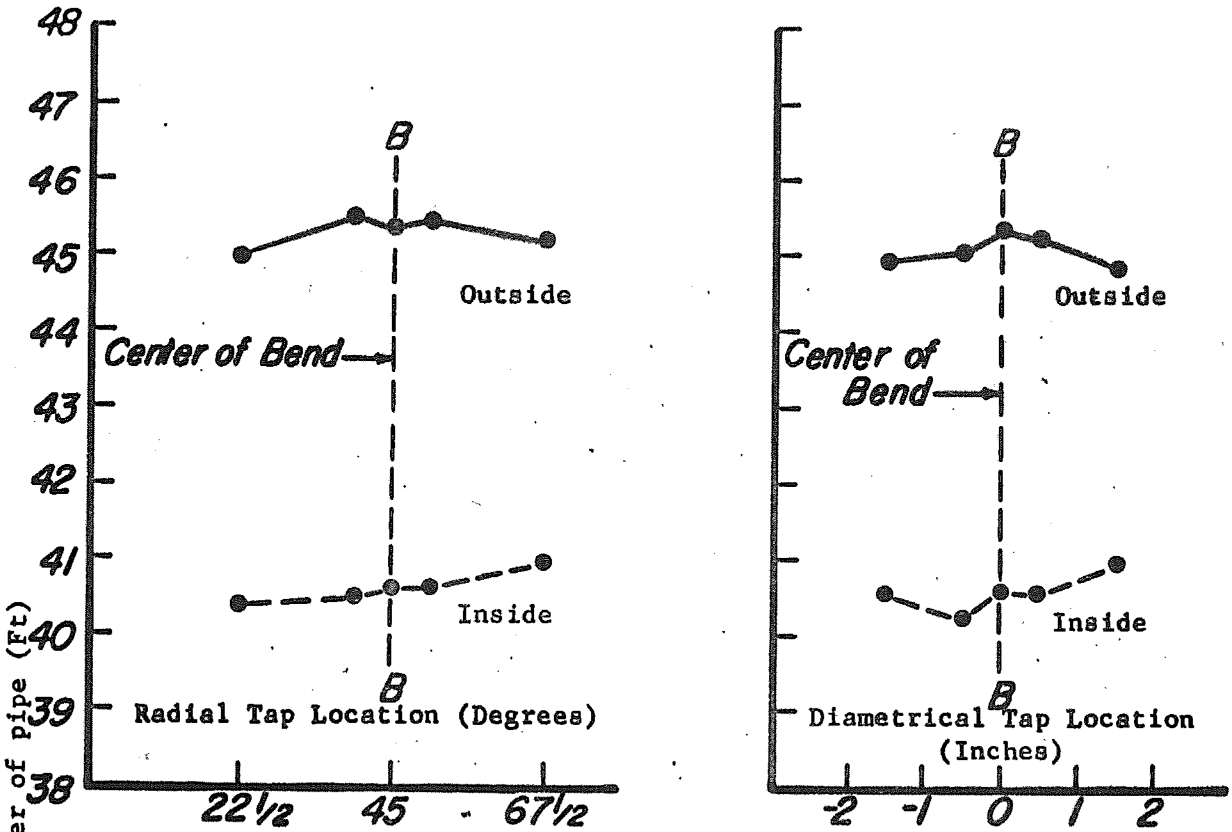
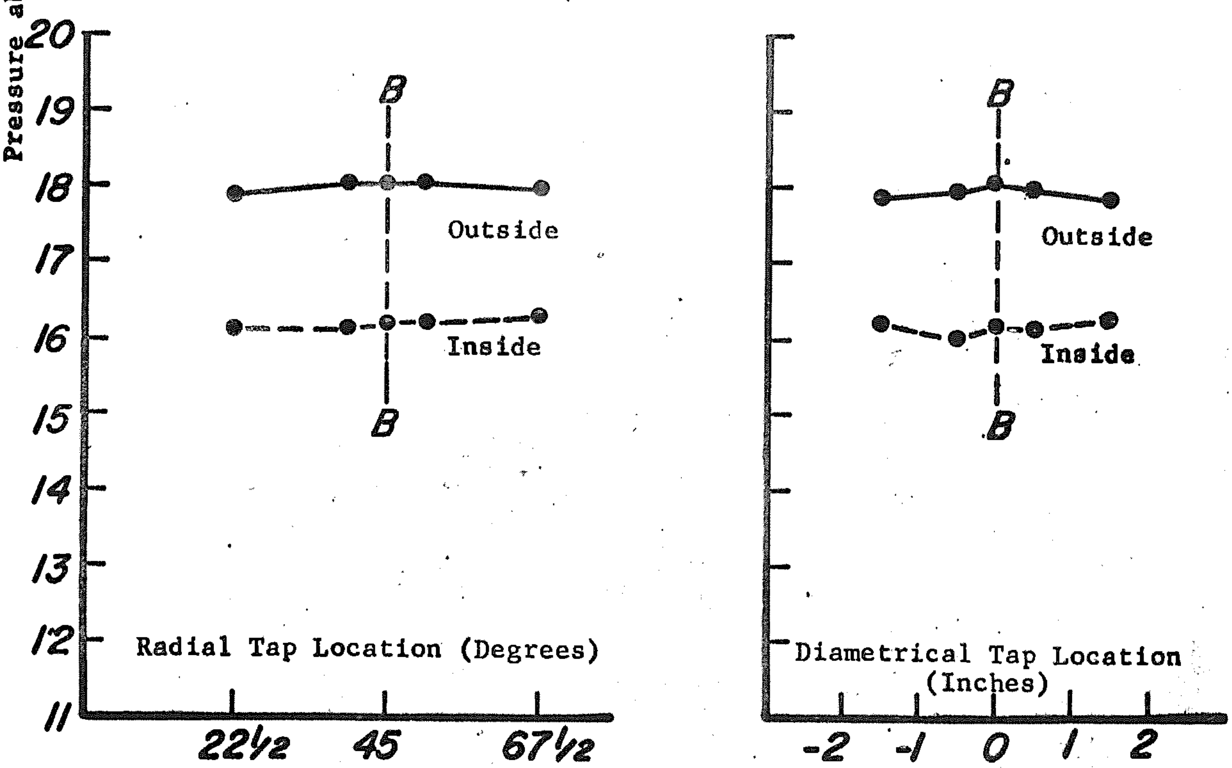


Figure 1. Location of pressure taps on 3" cast iron flanged 90 degree short radius elbow.



Pressure on inside and outside bends of elbow meter at 0.723 cfs.



Pressure on inside (Broken line) and outside (Solid line) bends of elbow meter at 0.446 cfs.

TITLE: UTILIZATION OF LIMITED WATER SUPPLIES FOR THE GREATEST ECONOMIC RETURN IN THE IRRIGATION OF COTTON

* LINE PROJECT: SWC 4-gG 5 CODE: Ariz.-WCL-21

INTRODUCTION: See previous Annual Reports

OBJECTIVES:

1. To study the influence of various soil-moisture treatments on certain visible plant symptoms for possible use in indicating need for irrigations on Acala 44-10 and Deltapine cotton.

2. To correlate the mean soil moisture in the root zone with desirable irrigation schedules.

3. To study the blossom and boll characteristics under various irrigation schedules.

PROCEDURE:

The experiment was located at the University of Arizona Cotton Research Center, Tempe, Arizona. Acala 44-10 and Deltapine cotton were planted in 4-row plots with 8 different irrigation treatments replicated 5 times. Nitrogen was applied previous to planting at 3 different levels (33#, 100#, 300#) on Deltapine and at the 100# level on Acala 44-10.

Irrigation Treatments

1. Irrigate when 85% of the available water has been used from the top 3 feet of root zone. 5/29, 7/12, 8/3, 9/11.

2. Irrigate when 75% used. 5/29, 7/6, 7/19, 8/11, 9/11.

3. Irrigate when 65% used. 5/29, 6/30, 7/19, 8/8, 9/11.

4. Irrigate when 50% or less is used. 5/29, 6/20, 7/6, 7/19, 8/3, 8/18, 9/11.

*DPL throughout paper should read DSL.

5. Irrigate at 65% used but do not fully replenish root zone. 5/29, 6/30, 7/19, 8/8, 9/11.

6. Irrigate when 65% used with final irrigation in early August. 5/29, 6/30, 7/19, 8/8.

7. Irrigate when 50% used with final irrigation in early August. 5/29, 6/20, 7/6, 7/19, 8/3.

8. Irrigate when 65% used until after first blossom peak, stress until blossoms appear again, then continue at 65% level. 5/29, 6/30, 7/19, 8/11, 9/11.

Tagging Treatments

1. All blossoms were tagged every day during the fruiting season on treatments 3 and 4 on both varieties at the 100# N level. Each mature boll was harvested separately for processing to determine blossom to boll efficiency.

2. The blossoms on all other treatments on both varieties and all fertilizer levels were counted every day. On the first day of every week a maximum of 10 tags were put on these plots. All bolls were harvested, counted and weighed.

Soil moisture measurements were made in all irrigation treatments at the 100# N level in both varieties.

Previous to planting, cotton stalks were pulverized and disked under. The field was plowed, fertilized with 185 pounds of Urea per acre and chiseled diagonally. It was then furrowed out, preplant irrigated and planted April 7th. An excellent stand was obtained and rows were thinned by hand chopping.

Water was held on the field 5 hours for the first irrigation, 6 hours on the second, and 12, 18 and 12 hours for subsequent irrigations on treatment 3. The water was not held on long enough during the second irrigation and penetration was inadequate.

Cultural practices included 8 sprayings and 3 dustings all by aerial application for control of cotton predators. The field was cultivated 4 times.

Yield measurements were made on 2 rows, 80 feet long within all irrigation, fertilizer and variety treatments. Yield plots were hand picked 3 times.

DISCUSSION:

The cotton grew slowly this year because of cool weather in April; however, blossoming was not delayed. Deltapine did not show appreciable differences in plant height regardless of irrigation treatment or amount of Nitrogen. The Acala showed difference in plant height due to irrigation treatments. The more water the taller the plant. Stressed irrigation treatments had short side branches.

SUMMARY AND CONCLUSIONS:

1. An analysis of variance between varieties showed no significance (Table 1). There was significance between irrigation under all fertility levels (Table 2). The 33-pound nitrogen fertility level was significantly lower than the 100 and 300 pound levels. There was no significance between 100 and 300 pounds. The irrigation treatments, if ranked according to yield, are similar under all fertility and varieties, with treatment 3 and those very similar being highest and treatments 1 and 5 lowest. The moisture stressed

treatments showed a trend that Acala takes a stress better than Deltapine.

2. Irrigation schedules for treatments 3 and 5 were identical. The difference between them was the time of set for the third and fourth irrigations. Treatment 5 was irrigated only 1/2 as long as 3 on July 19 and August 8.

Irrigation Dates	Hours Set		Soil-Moisture Status	
	Trt. 3	Trt. 5	Trt. 3	Trt. 5
May 29	5	5	similar	similar
June 30	6	6	similar	similar
July 19	12	6	3 feet	2 feet
Aug 8	18	8	5 feet	2 feet
Sept 11	12	12	similar	similar

The following reductions in yield due to inadequate penetration of water in treatment 5 as compared to treatment 3.

DPL - 30# N - 12.5 per cent
DPL - 100# N - 17.0 per cent
DPL - 300# N - 28.0 per cent
Acala - 100# N - 14.9 per cent

3. Irrigations on treatment 3 and 6 were similar until September 8 when treatment 3 was given a final irrigation. Treatments 4 and 7 were similar through August 18 when treatment 4 was given an irrigation followed by one more September 11. Treatments 3 and 4 out-yielded 6 and 7 under all fertility levels. Treatment 8 also out-yielded 6 and 7 (Table 2). Treatments 6 and 7 were included in the experiment to check the validity of giving and irrigation on DPL after the first week of August. The data indicates DPL should have water for late season use to obtain maximum production just

as the Acala varieties.

4. Blossom data figures show that DPL does put on a considerable number of blossoms late in the year. Low nitrogen reduced the total number of blossoms irregardless of the irrigation treatments (Table 3). The 85% used stress treatment was significantly lower in blossom on all fertilizer and variety treatments. There is significance at the 5% level between irrigations but no significance between varieties in total blossom analysis (Table 4). Figures 2 through 5 show blossom production. Treatment 3 has the most desirable blossom rate. The big difference is that treatment 3 had a blossoming period in August when the other treatments did not. The data shows that high blossoming does not occur when the nitrogen fertilizer is inadequate even though the irrigation water management is correct.

5. Blossom and boll data are being processed. Figures 6, 7, 8 and 9 show that DPL puts on a good set of bolls earlier than Acala. A good set was achieved by the first week of July. The Acala variety had its first peak about the 20th of July. A definite blossoming and boll set was obtained in August for treatment 3 but not treatment 4. Treatment 4 had a more efficient boll rate during the second week of July and ended up with the same number of bolls as treatment 3. On the basis of treatments 3 and 4, Acala has about 30% less pickable bolls than DPL.

6. Consumptive use for 1961 was slightly lower than the long time average. When optimum irrigation schedules were used (Trts 3, 6 and 8) the consumptive use for the two varieties was similar (Table 5). When plants were stressed or over irrigated the Acala variety used

more water (approximately 4 acre inches per season). The water used from the different soil profiles were similar for the two varieties. The Acala seemed to have a more pronounced peak use than the DPL. The DPL had a relatively flat peak which moves forward when the plants are stressed for water (Figures 10 through 14). Treatment 85 per cent and 75 per cent used DPL peaked during the latter part of August when the plant was fruiting very poorly.

PERSONNEL: L. J. Erie, F. French, USDA, and L. Patterson, University of Arizona.

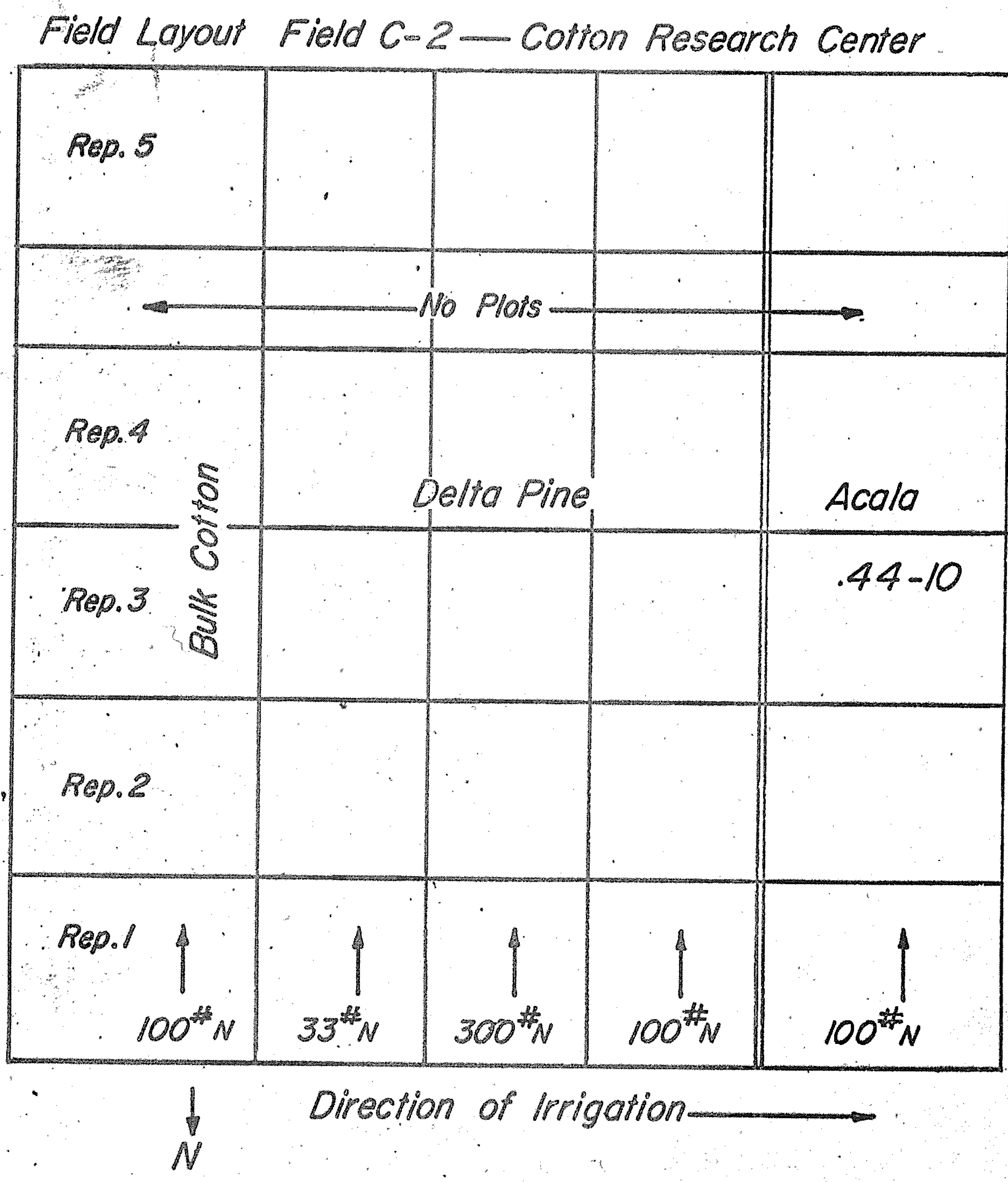

Field Layout Field C-2 — Cotton Research Center
Rep. 5
No Plots
Rep. 4
Delta Pine
Acala
Bulk Cotton
Rep. 3
44-10
Rep. 2
Rep. 1
100#N
33#N
300#N
100#N
100#N
Direction of Irrigation
N

Table 1. Analysis of Variance - Lint Cotton on 100# Nitrogen

Variety	Irr Trts	Replications 1	2	3	4	5	Mean
	1	12.08	12.00	14.27	11.86	10.38	12.12
	2	15.37	16.19	15.12	12.52	11.69	14.18
	3	14.82	18.40	20.02	15.78	13.92	16.59
	4.	19.06	17.54	17.30	15.96	11.84	16.34
DPL	5	15.48	12.00	16.48	13.86	10.90	13.74
	6	12.45	16.19	17.98	16.53	10.57	14.74
	7	14.03	15.23	16.96	16.34	13.46	15.20
	8	15.64	16.61	17.22	15.32	13.04	15.57

Variety	Irr Trts	Replications 1	2	3	4	5	Mean
	1	10.08	16.13	16.64	16.32	9.90	13.81
	2	13.30	15.51	16.96	15.76	13.05	14.91
	3	12.49	17.74	18.65	16.90	14.46	16.05
44-10	4	18.66	17.13	17.87	16.42	13.25	16.67
	5	12.19	16.24	16.39	14.89	8.32	13.61

Variety	Irr Trts	Replications 1	2	3	4	5	Mean
	6	10.69	17.79	17.75	19.02	12.86	15.62
	7	11.46	15.84	16.06	16.63	10.79	14.16
	8	13.91	15.41	15.68	14.67	10.95	14.12

Variety - no. sig. 5% = 2.77

Irrigation - sig. 1% 1% = 3.68

Irrigations variety - no sig.

Table 2. Analysis of Variance DPL - Fertilizers

Reps.	1	2	3	4	5	6	7	8	Fertilizer
	Irrigation Treatments								
1	14.93	15.06	16.15	15.75	14.07	15.66	14.61	18.33	
2	12.74	13.41	12.87	12.88	11.53	12.75	12.72	15.01	
3	10.79	11.59	12.73	12.17	11.97	11.88	12.83	12.85	
4	9.77	8.89	12.47	11.13	11.63	11.83	11.02	9.49	N-33
5	6.17	8.26	9.83	8.00	6.95	6.95	7.65	8.00	
Mean	10.88	11.44	12.81	11.99	11.23	11.81	11.77	12.74	11.83
Bales/A	1.92	2.02	2.26	2.12	1.99	2.09	2.08	2.25	
1	16.33	14.73	17.44	17.33	12.54	15.36	14.62	17.17	
2	13.68	16.56	16.73	15.90	13.91	16.87	16.26	14.93	
3	13.12	13.10	17.59	15.52	12.17	17.64	13.74	15.19	
4	11.23	11.52	14.48	15.39	11.81	14.65	15.88	12.06	N-300
5	9.32	11.81	16.13	12.17	8.82	6.37	13.31	14.40	
Mean	12.74	13.54	16.47	15.26	11.85	14.18	14.76	14.75	14.19
Yield Bales/A	2.25	2.39	2.91	2.70	2.10	2.51	2.61	2.61	
1	11.17	14.22	13.71	17.63	14.32	11.52	12.98	14.47	
2	11.10	14.98	17.02	16.22	11.10	14.98	14.09	15.36	
3	13.20	13.99	18.52	16.00	15.24	16.63	15.69	15.93	N-100
4	10.97	11.58	14.60	14.76	12.82	15.29	15.11	14.17	
5	9.60	10.81	12.88	10.95	10.08	9.78	12.45	12.06	
Mean	11.21	13.12	15.35	15.11	12.71	13.64	14.06	14.40	13.70
Bales/A	1.98	2.32	2.71	2.67	2.25	2.41	2.49	2.55	

Fertilizers sig. 5% — LSD Fertilizer = 1% = 3.42

Irrigations sig. 1% — 5% = 2.35

Irrigations and Fertilizers no sig. — LSD Irrigation = 1% = 3.30

5% = 2.49

Table 3. Blossoms on DPL-15.

	Fertilizers 100#	300#	33#
Irr. Trts.	Means (Irrigation)		
1	619	639	516
2	665	730	578
3	741	758	567
4	664	699	578
5	672	678	573
6	688	703	572
7	662	657	597
8	694	694	620
Fertilizer Means	677	695	575

Fertilizer sig. 1%

LSD Fertilizer 1% 177.14
5% 121.14

Irrigation sig. 1%

Irrigation and Fertilizer no sig.

LSD Irrigation 1% 76.97
5% 58.08

Table 4. Blossom Analysis between DPL-15 and 44-10 (100#N).

Irr Trts.	Variety 44-10	Variety DPL-15
	Means	
1	572	619
2	663	678
3	745	741
4	730	664
5	647	672
6	714	688
7	701	662
8	679	694

Variety no sig. LSD-Irrigation 1% 100.96

Irrigation sig. 1% 5% 76.18

Irrigation and Variety no sig.

Table 5. Summary of Consumptive Use (acre inches).

Irrigation Trts.	100# Nitrogen Variety DPL	Acala 44-10
1	27.51	31.46
2	29.18	34.45
3	35.01	34.60
4	34.67	41.50
5	30.80	33.54
6	29.80	29.98
7	26.95	31.41
8	35.02	36.42

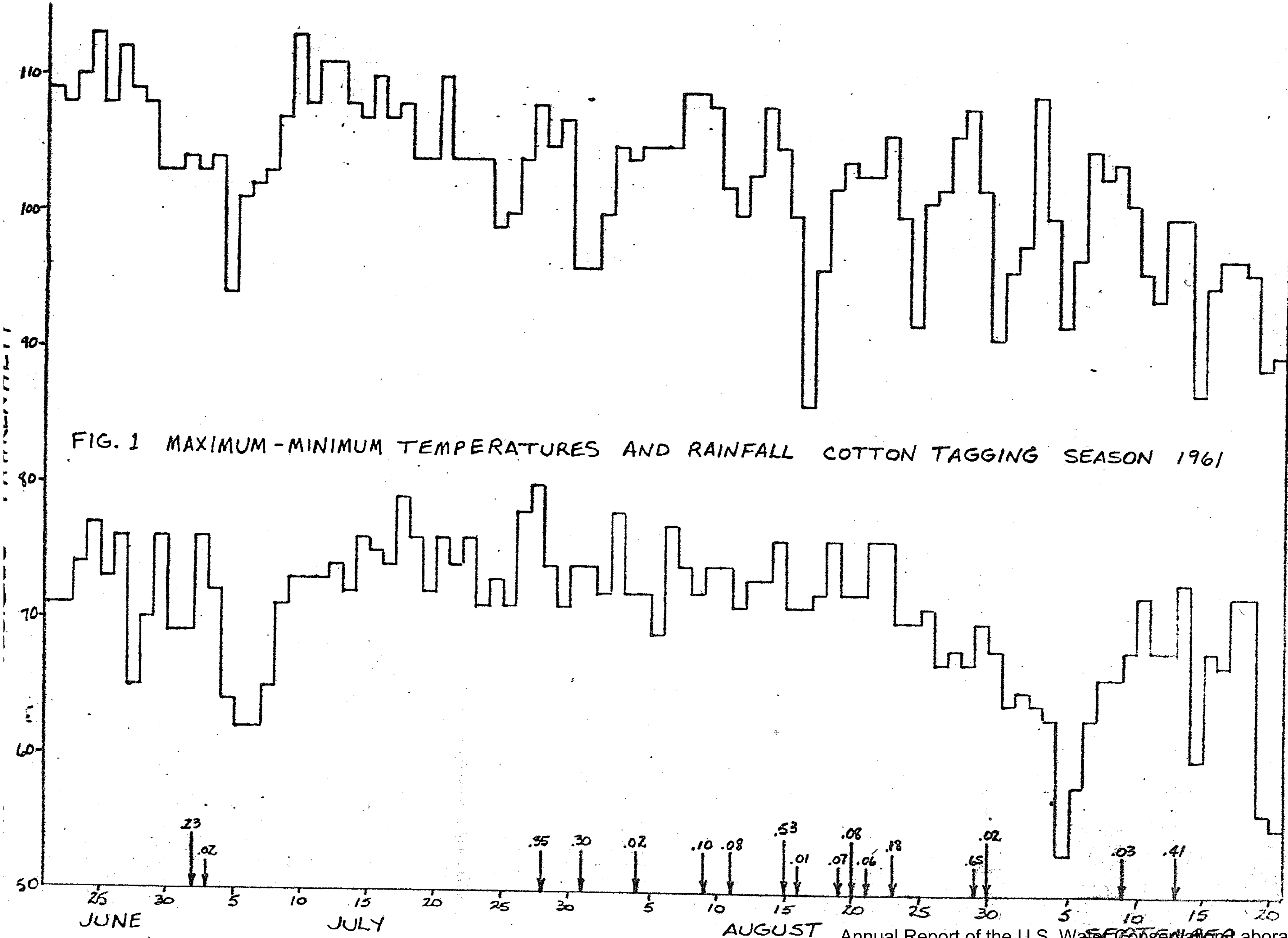


FIG. 1 MAXIMUM - MINIMUM TEMPERATURES AND RAINFALL COTTON TAGGING SEASON 1961

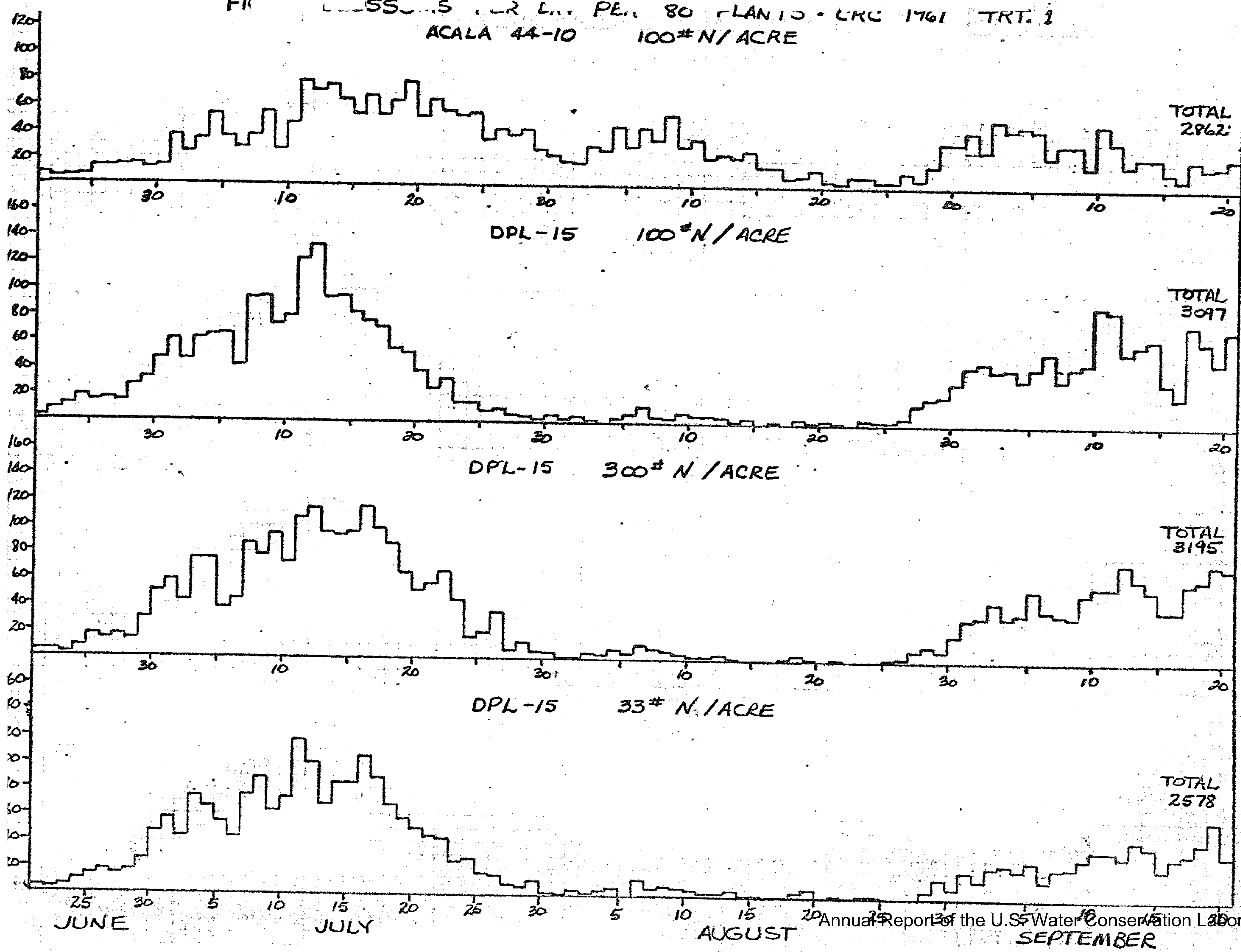
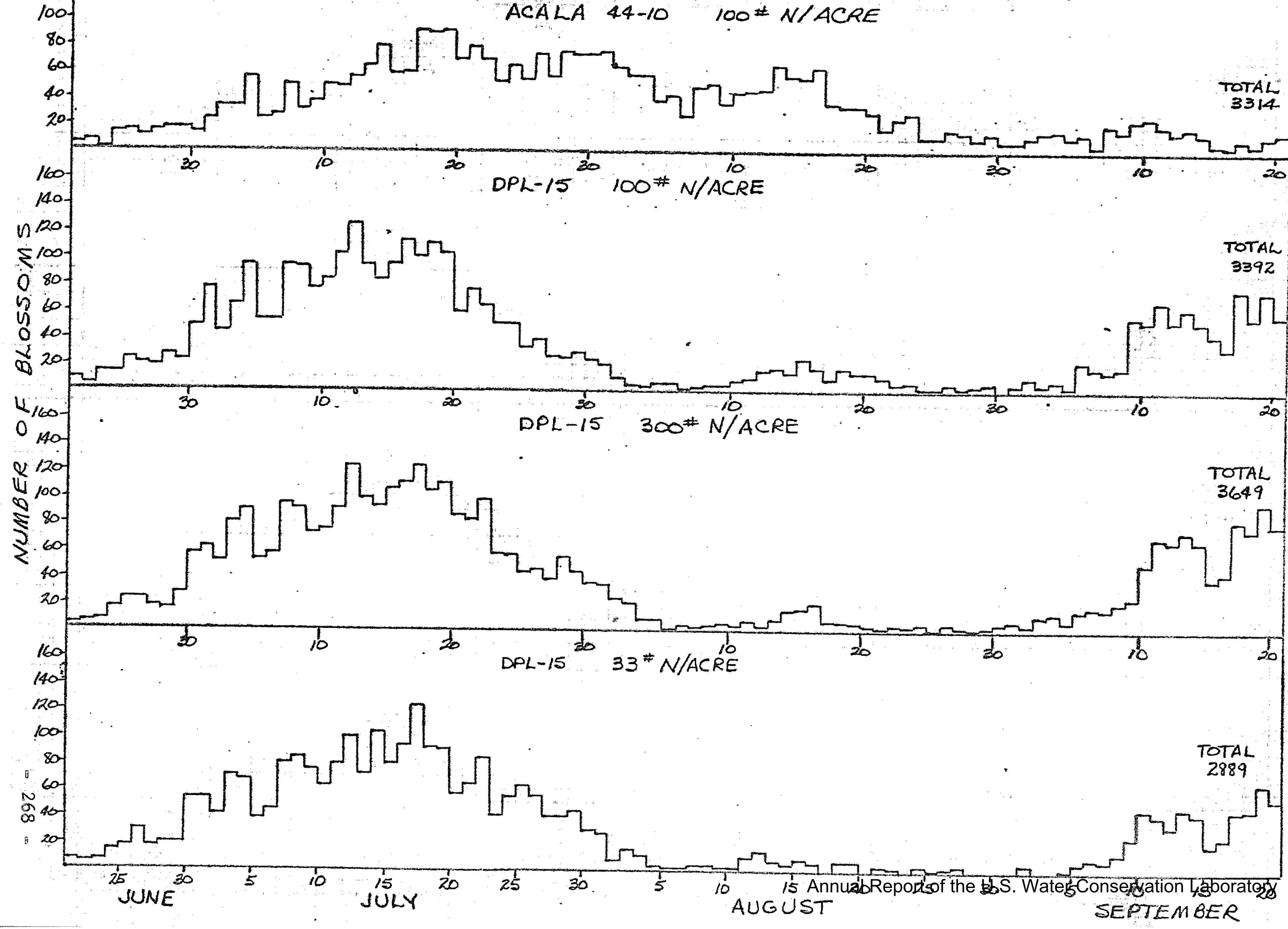

TRT. 1
ACALA 44-10 100# N/ACRE
TOTAL 2862
DPL-15 100# N/ACRE
TOTAL 3097
DPL-15 300# N/ACRE
TOTAL 3195
DPL-15 33# N/ACRE
TOTAL 2578
JUNE
JULY
AUGUST
SEPTEMBER

FIG. 3 BLOSSOMS PER DAY PER 80 PLANTS CRC 1961 TRT. 2



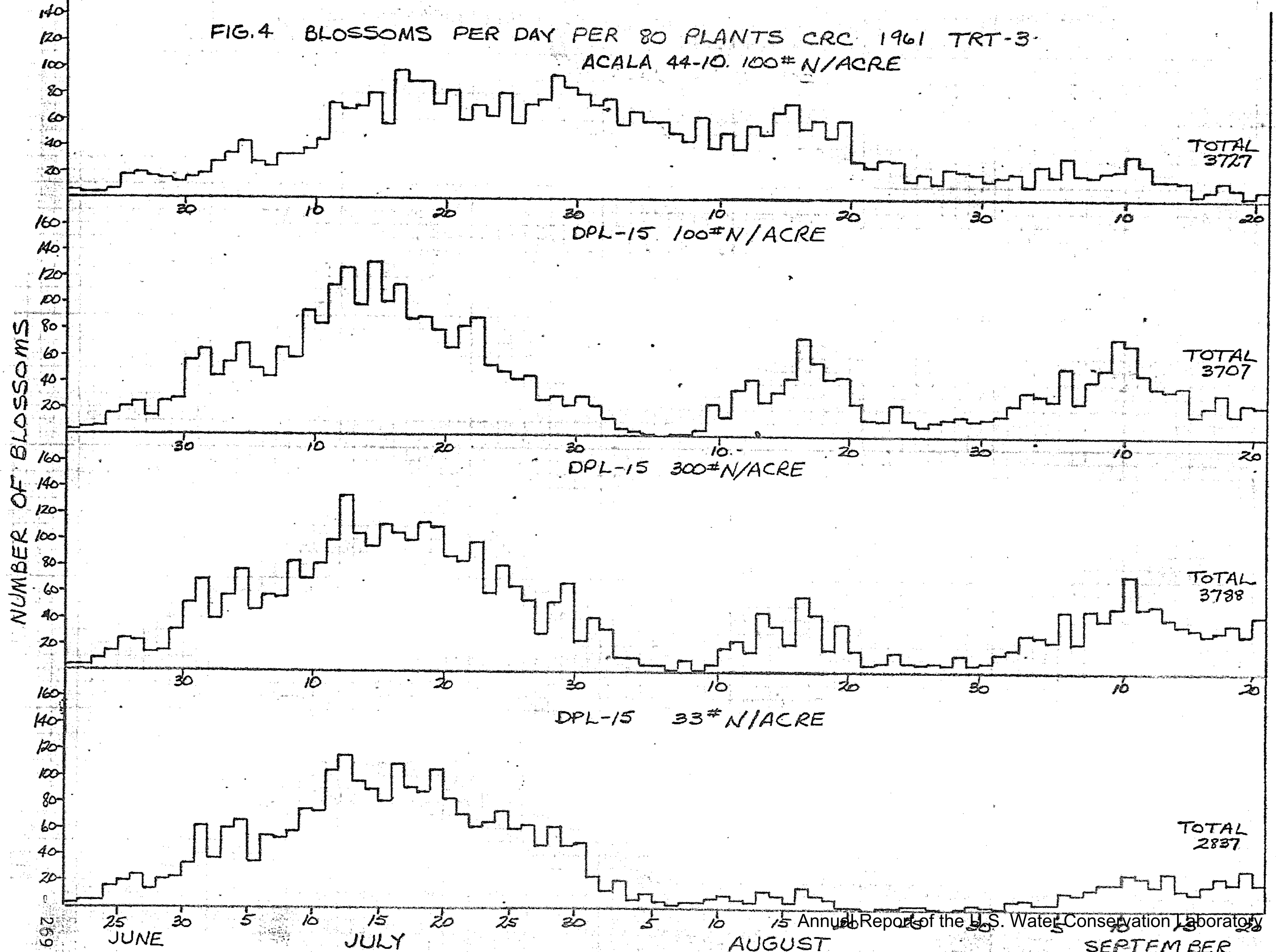


FIG. 4 BLOSSOMS PER DAY PER 80 PLANTS CRC 1961 TRT-3
ACALA 44-10. 100# N/ACRE
TOTAL 3727
DPL-15 100# N/ACRE
TOTAL 3707
DPL-15 300# N/ACRE
TOTAL 3788
DPL-15 33# N/ACRE
TOTAL 2837
NUMBER OF BLOSSOMS
JUNE
JULY
AUGUST
SEPTEMBER

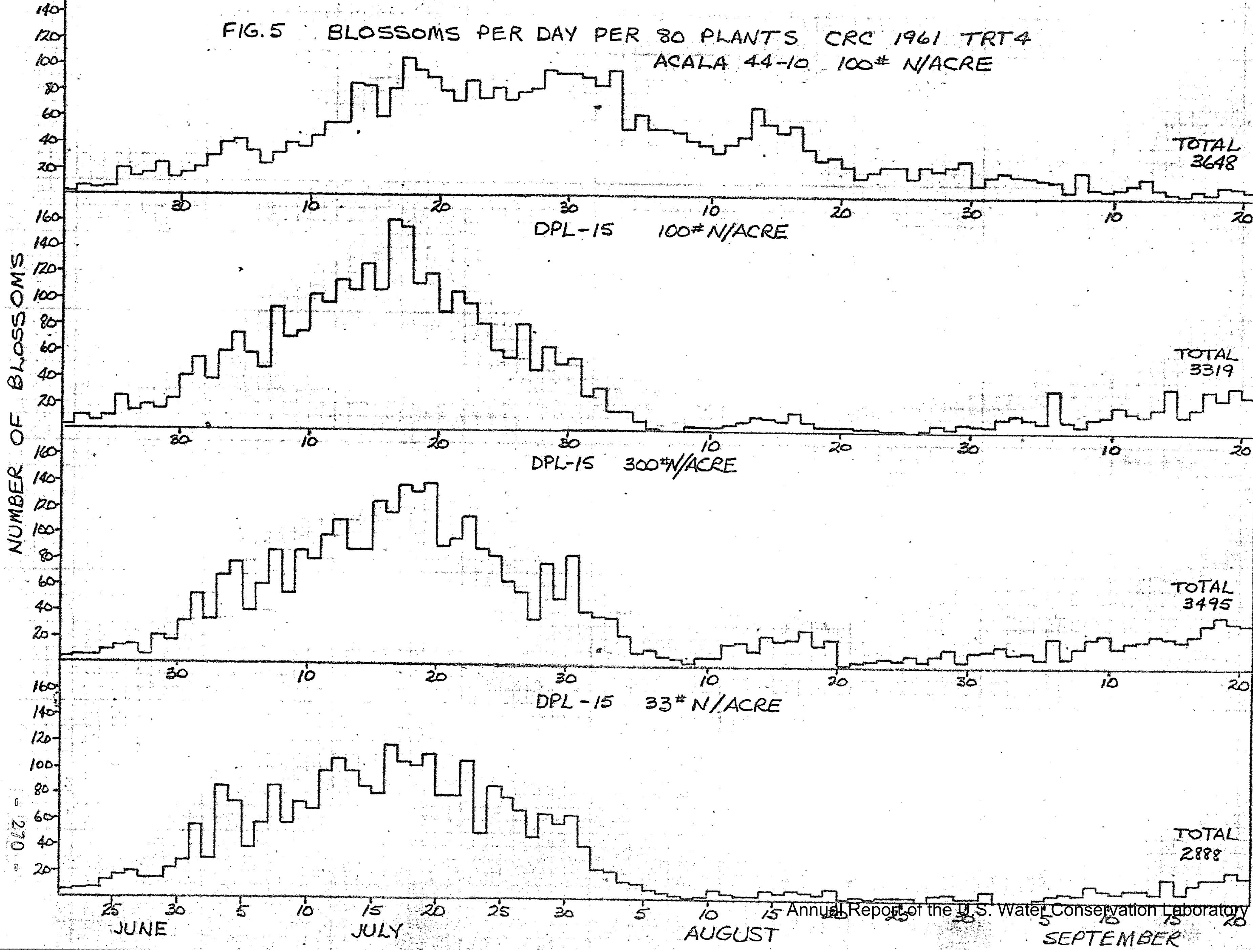


FIG. 5 BLOSSOMS PER DAY PER 80 PLANTS CRC 1961 TRT4
ACALA 44-10 100# N/ACRE
TOTAL 3648
DPL-15 100# N/ACRE
TOTAL 3319
DPL-15 300# N/ACRE
TOTAL 3495
DPL-15 33# N/ACRE
TOTAL 2888
NUMBER OF BLOSSOMS
JUNE
JULY
AUGUST
SEPTEMBER

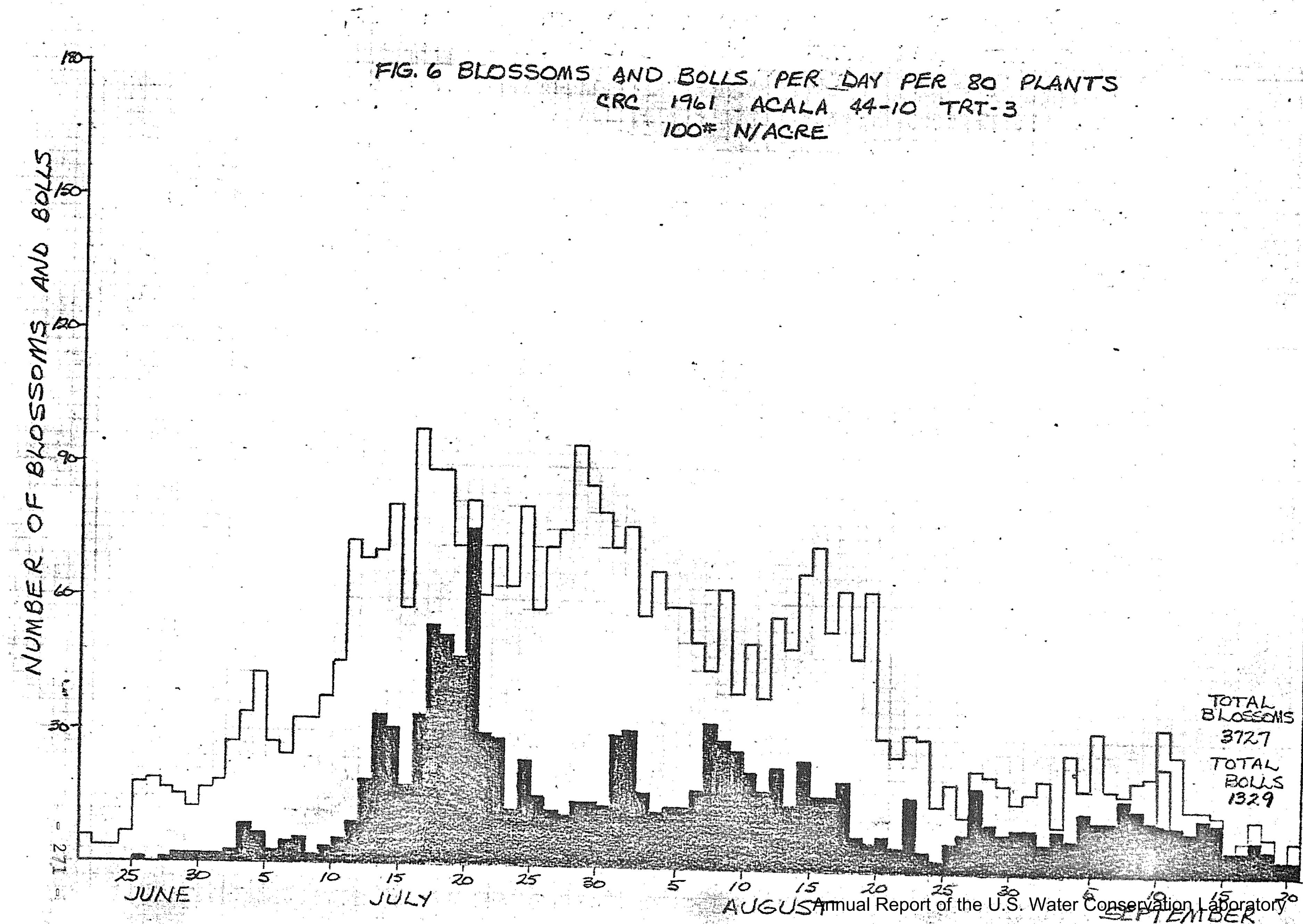
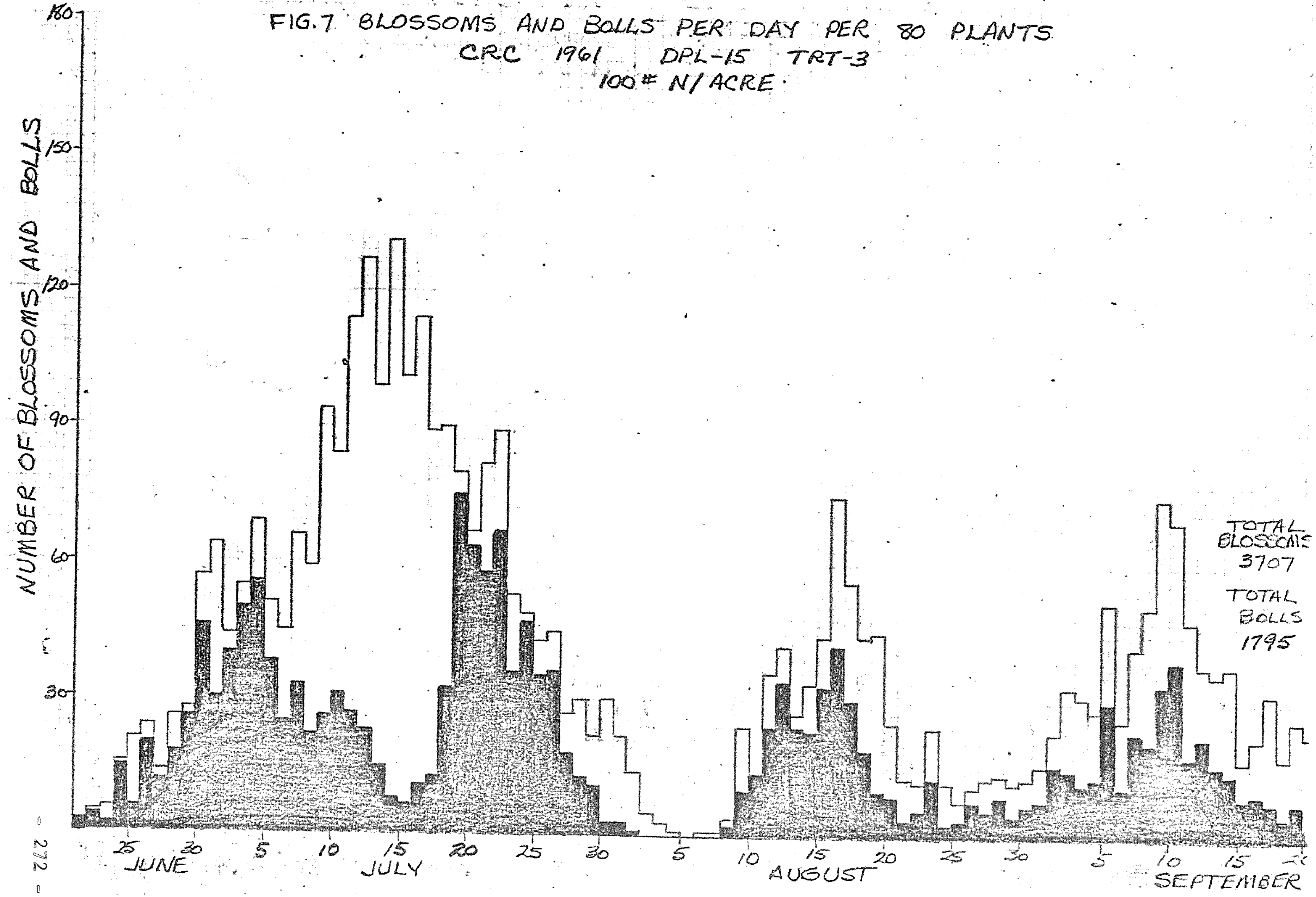


FIG. 6 BLOSSOMS AND BOLLS PER DAY PER 80 PLANTS
CRC 1961 ACALA 44-10 TRT-3
100# N/ACRE
NUMBER OF BLOSSOMS AND BOLLS
180
150
120
90
60
30
25
30
5
10
15
20
25
30
5
10
15
20
25
30
5
10
15
20
JUNE
JULY
AUGUST
SEPTEMBER
TOTAL BLOSSOMS 3727
TOTAL BOLLS 1329

FIG. 7 BLOSSOMS AND BOLLS PER DAY PER 80 PLANTS
CRC 1961 DPL-15 TRT-3
100# N/ACRE



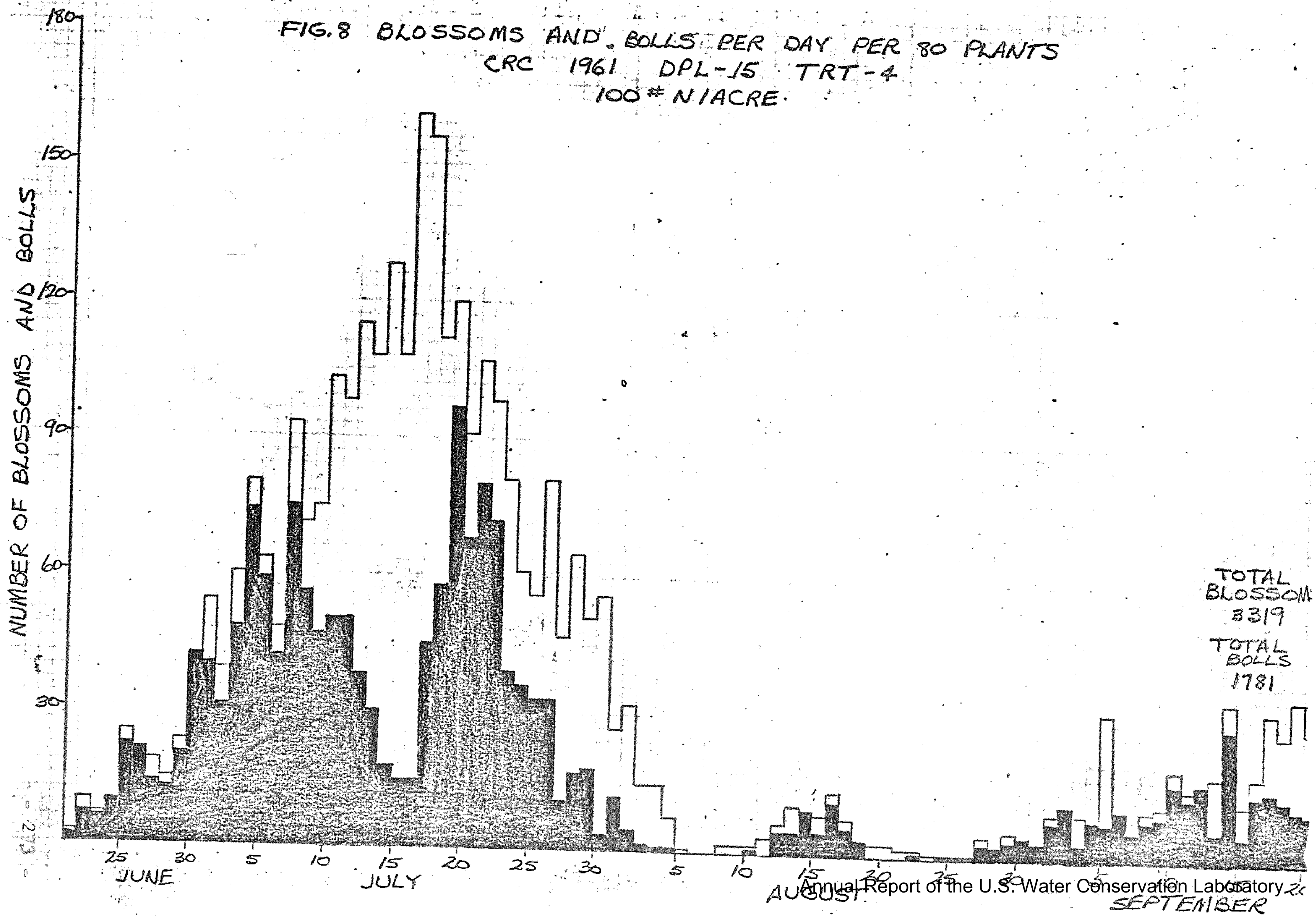


FIG. 8 BLOSSOMS AND BOLLS PER DAY PER 80 PLANTS
CRC 1961 DPL-15 TRT-4
100# N/ACRE
NUMBER OF BLOSSOMS AND BOLLS
180
150
120
90
60
30
25
30
5
10
15
20
25
30
5
10
15
20
25
30
5
10
JUNE
JULY
AUGUST
SEPTEMBER
TOTAL BLOSSOM
3319
TOTAL BOLLS
1781

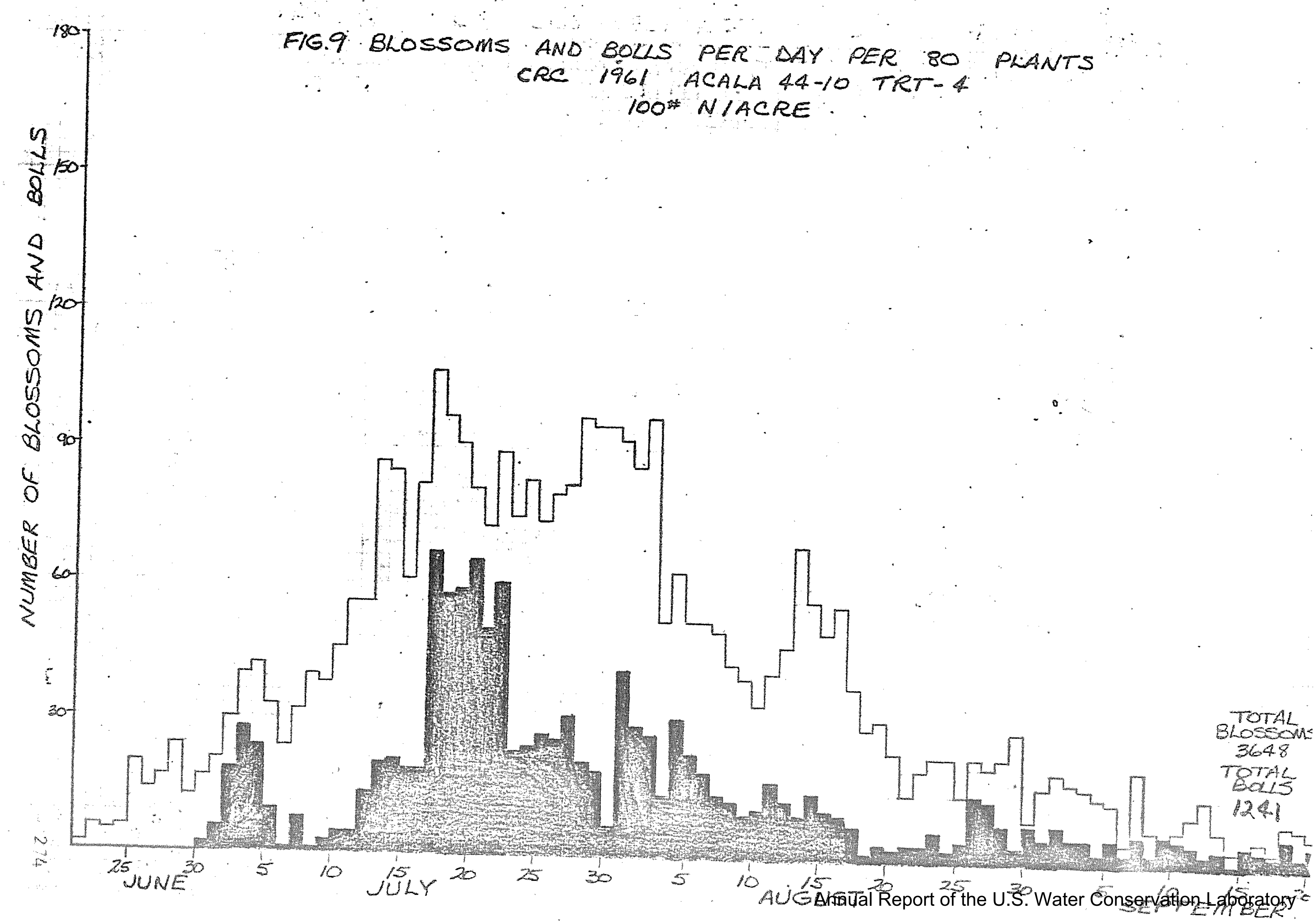


FIG. 9 BLOSSOMS AND BOLLS PER DAY PER 80 PLANTS
CRC 1961 ACALA 44-10 TRT-4
100# N/ACRE
NUMBER OF BLOSSOMS AND BOLLS
180
150
120
90
60
30
25
30
5
10
15
20
25
30
5
10
15
20
25
30
5
10
15
JUNE
JULY
AUGUST
SEPTEMBER
TOTAL BLOSSOMS 3648
TOTAL BOLLS 1241

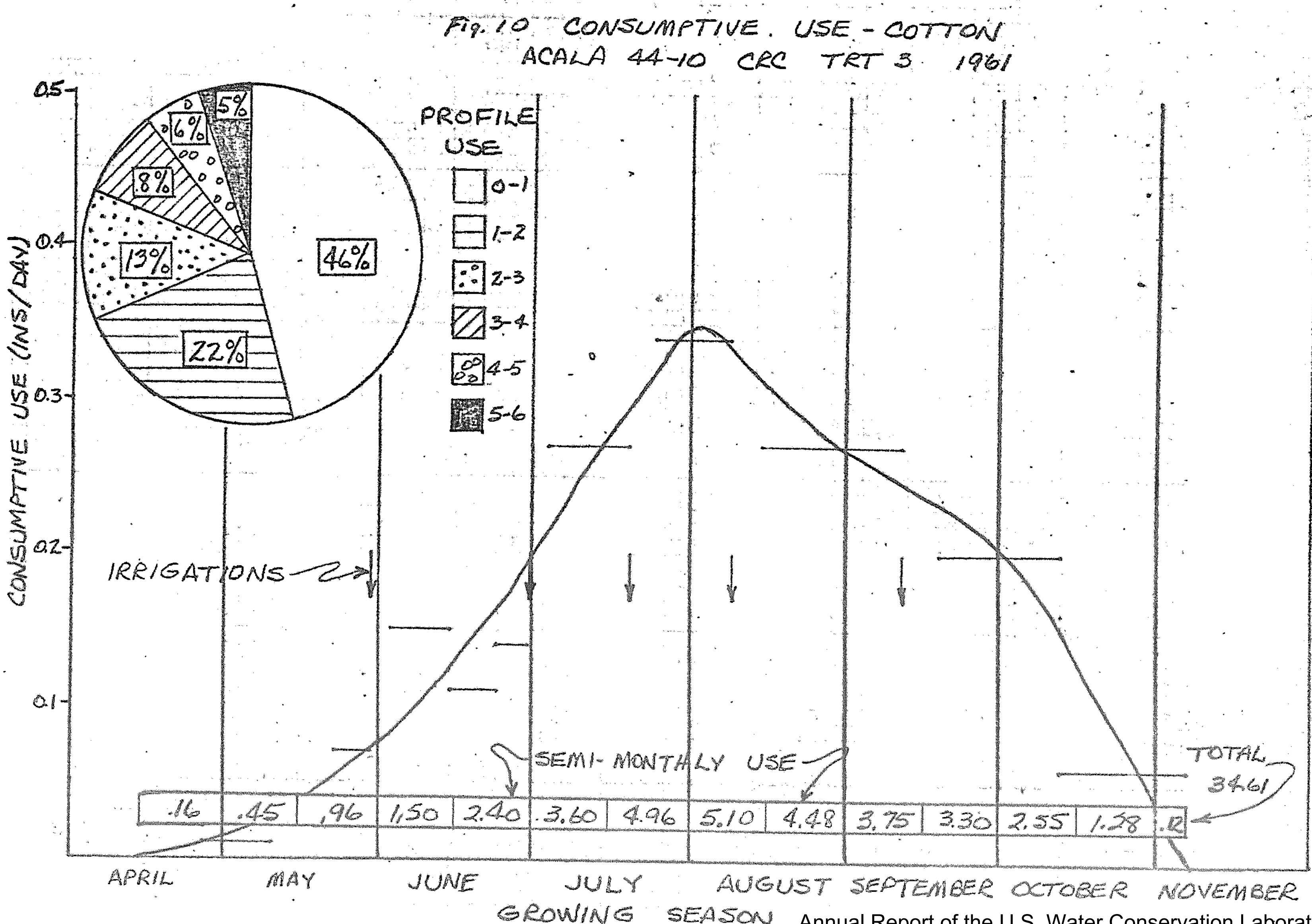
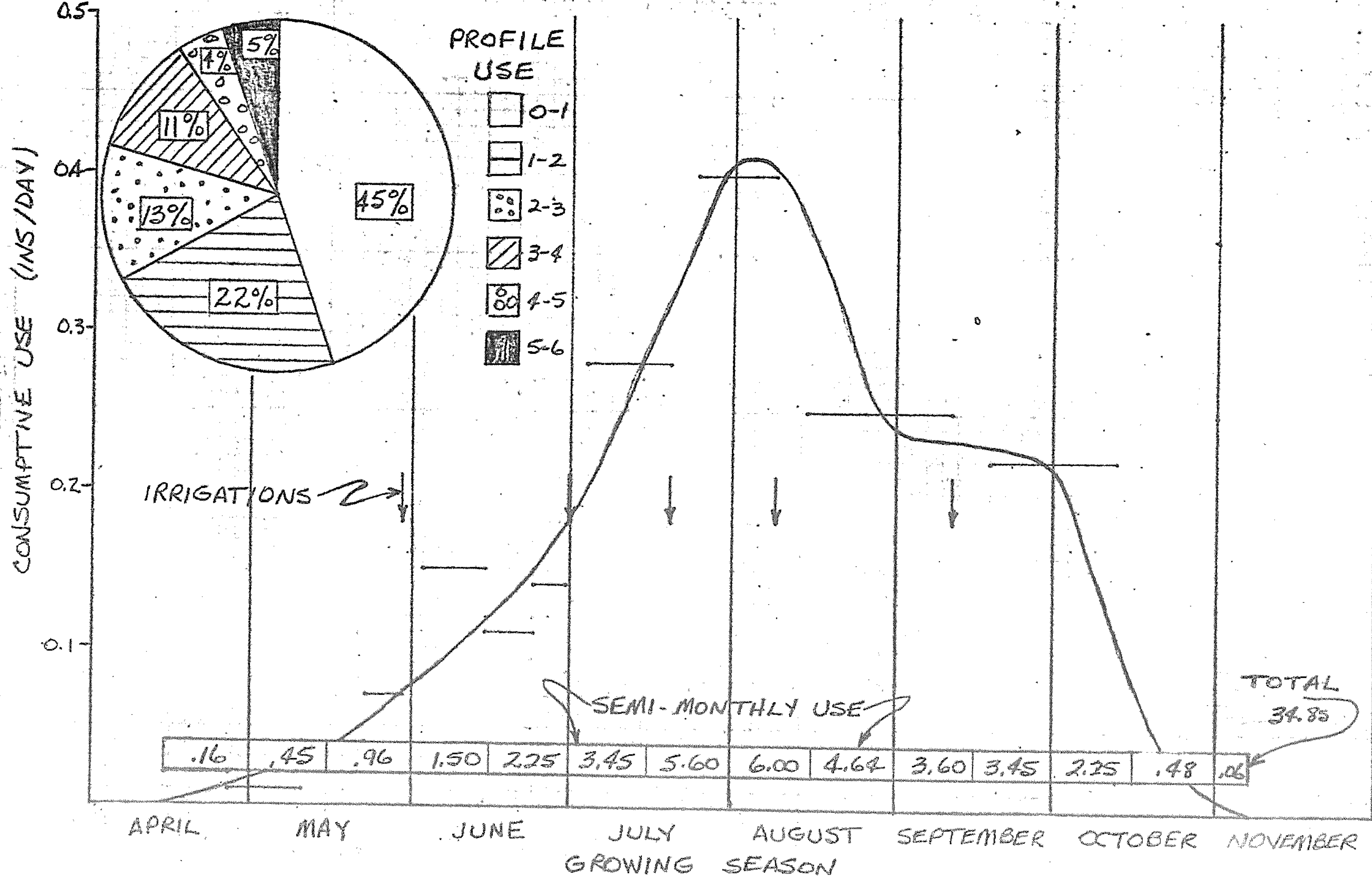


Fig. 10 CONSUMPTIVE. USE - COTTON
ACALA 44-10 CRC TRT 3 1961
PROFILE USE
0-1
1-2
2-3
3-4
4-5
5-6
46%
22%
13%
8%
6%
5%
CONSUMPTIVE USE (INS/DAY)
0.5
0.4
0.3
0.2
0.1
IRRIGATIONS
SEMI-MONTHLY USE
.16
.45
.96
1.50
2.40
3.60
4.96
5.10
4.48
3.75
3.30
2.55
1.28
.12
TOTAL 34.61
APRIL
MAY
JUNE
JULY
AUGUST
SEPTEMBER
OCTOBER
NOVEMBER
GROWING SEASON

- 275 -

Fig. 11 CONSUMPTIVE USE - COTTON
DPL-15 CRC TRT. 3 1961



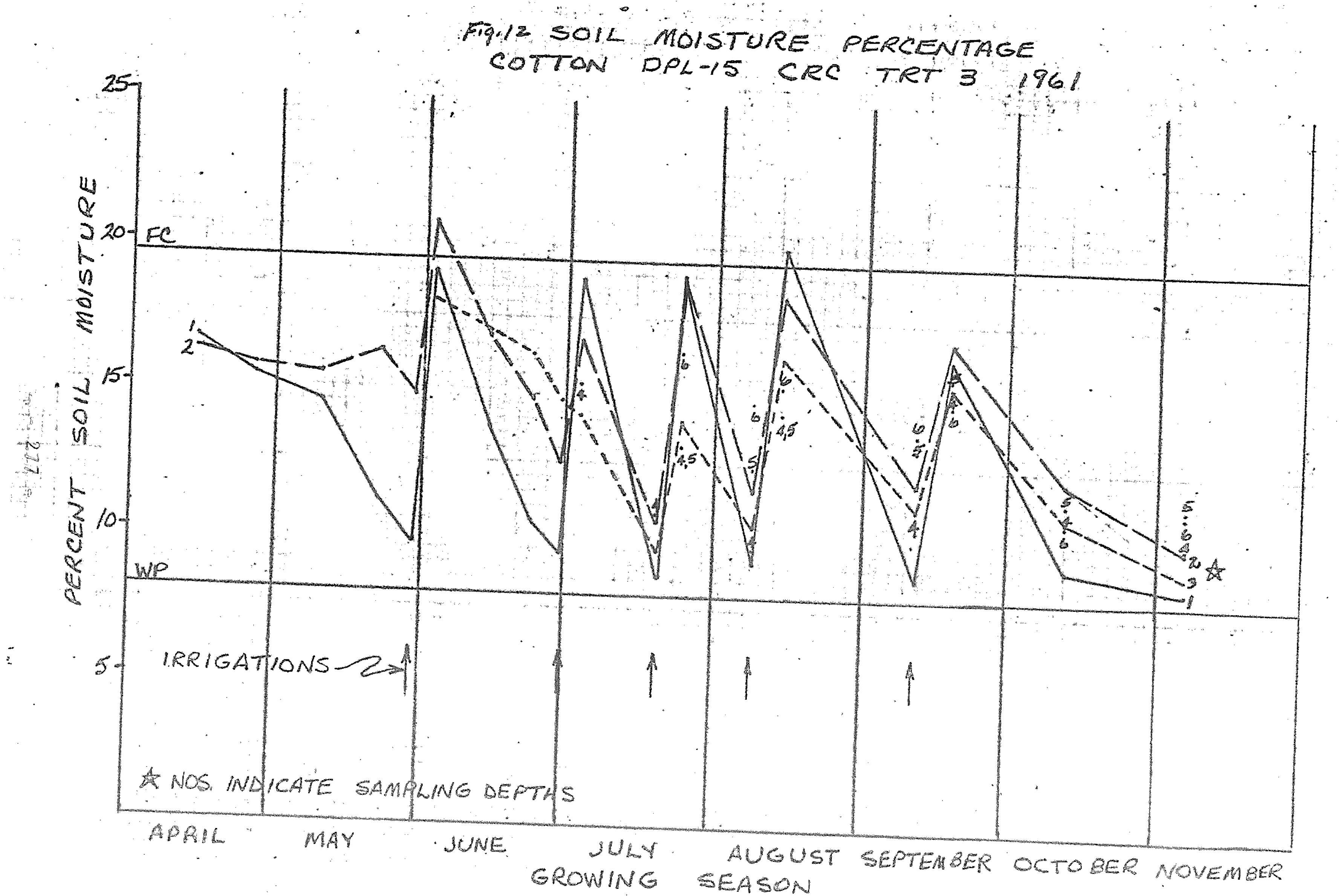
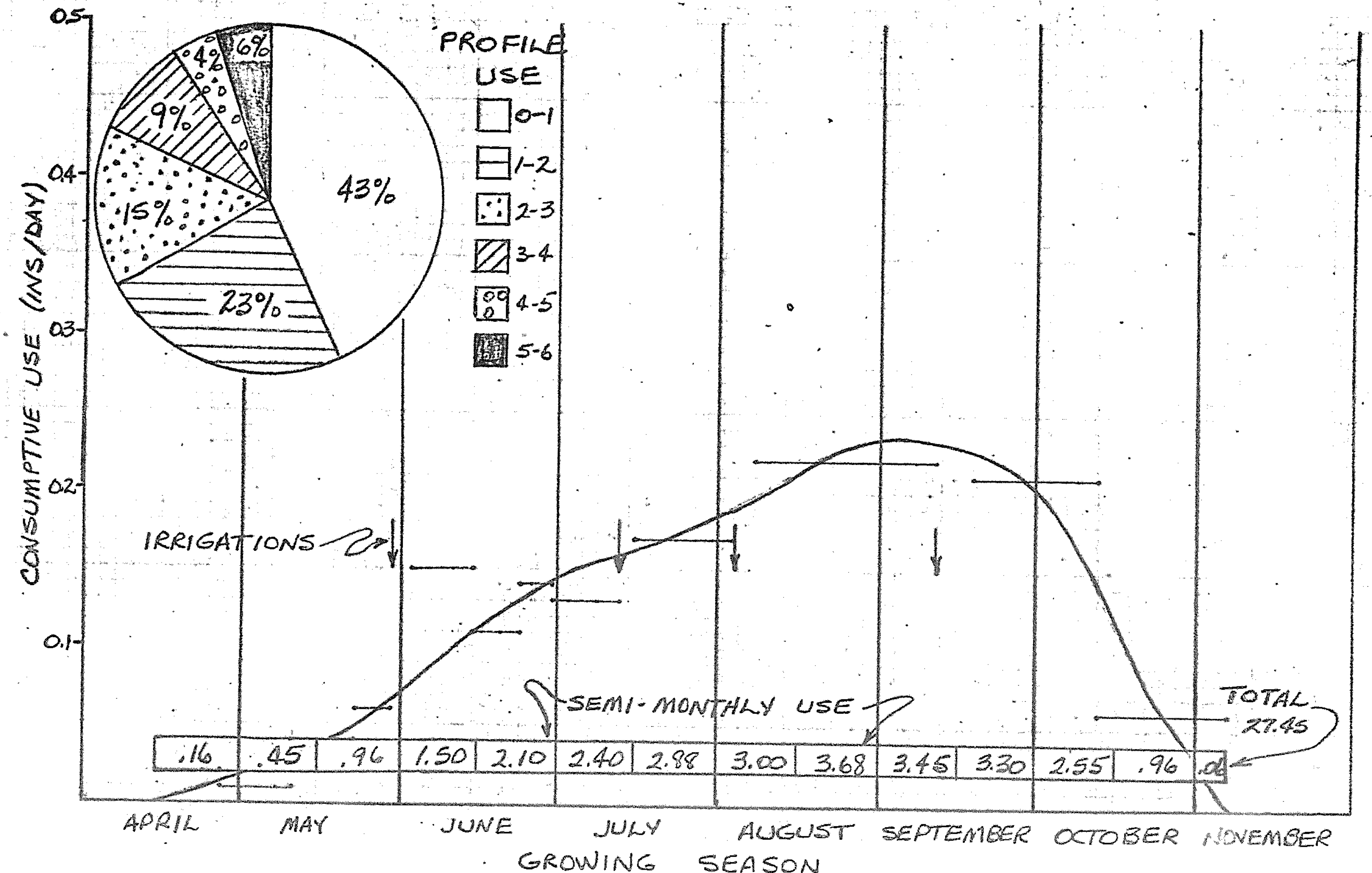


Fig. 12 SOIL MOISTURE PERCENTAGE
COTTON DPL-15 CRC TRT 3 1961
PERCENT SOIL MOISTURE
25
20
FC
15
10
WP
5
IRRIGATIONS
☆ NOS. INDICATE SAMPLING DEPTHS
APRIL
MAY
JUNE
JULY
AUGUST
SEPTEMBER
OCTOBER
NOVEMBER
GROWING SEASON

Fig. 13 CONSUMPTIVE USE - COTTON
DPL-15 CRC TRT 1 1961



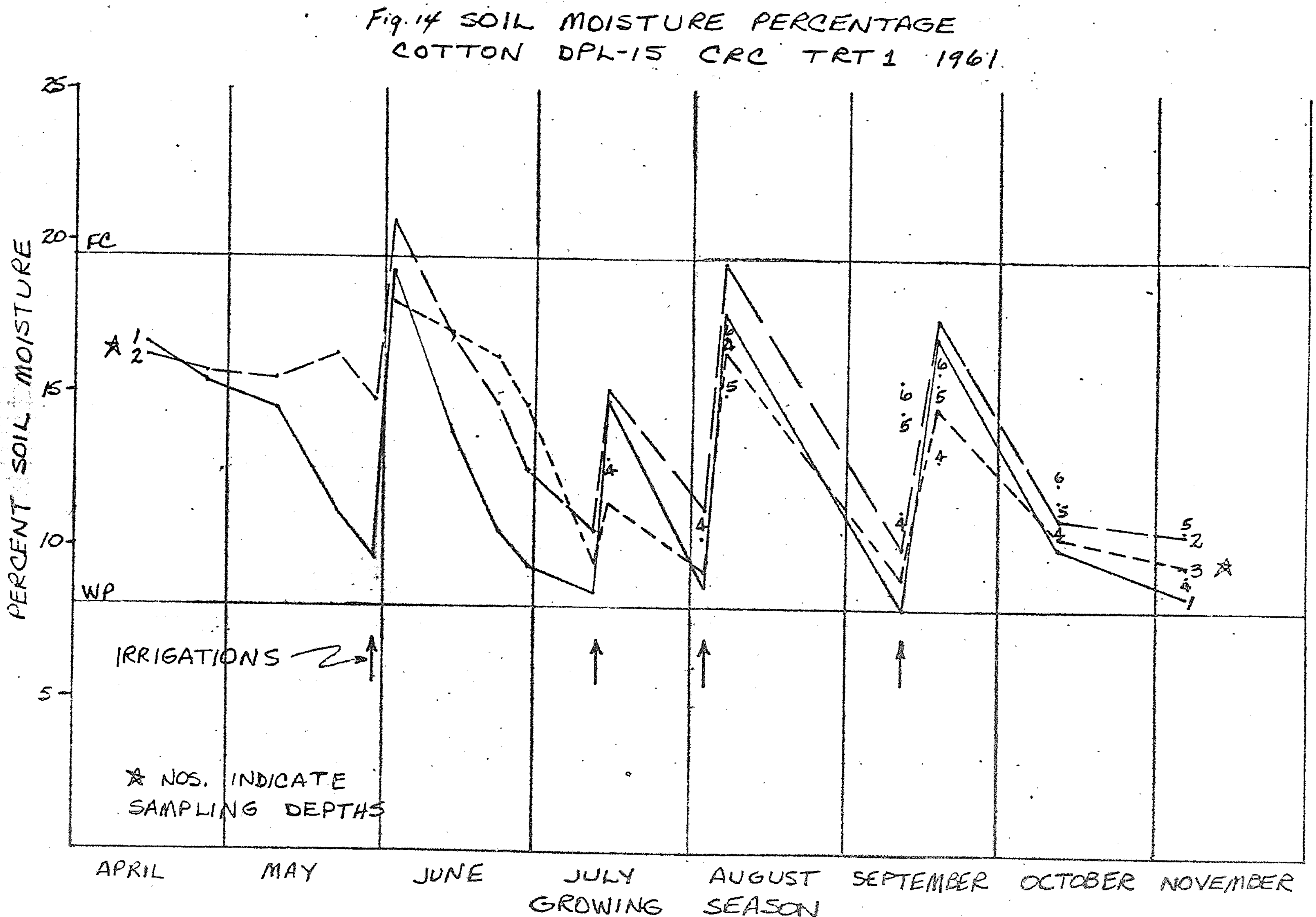


Fig. 14 SOIL MOISTURE PERCENTAGE
COTTON DPL-15 CRC TRT 1 1961
PERCENT SOIL MOISTURE
25
20
15
10
5
FC
WP
IRRIGATIONS
* NOS. INDICATE
SAMPLING DEPTHS
APRIL
MAY
JUNE
JULY
AUGUST
SEPTEMBER
OCTOBER
NOVEMBER
GROWING SEASON

TITLE: SOIL MOISTURE CONDITIONS AND ROOT ACTIVITY DISTRIBUTION PATTERNS

LINE PROJECT: SWC 11-gG1 CODE NO.: Ariz.-WCL-1

INTRODUCTION:

A discussion of the theory, experimental design and procedures is presented in the Annual Report for 1960. The experiment differed from the 1960 study in that a lower irrigation level was used and the amount of water applied was accurately measured. Radioactive solution injection patterns were also modified to obtain root activity at a greater depth and at a location within the plant row.

PROCEDURE:

Four low levels of irrigation of three replicates each were located on a 64- × 275-foot plot. The replicate plot size was 90 feet by 32 feet and contained 18 depth-distance injection treatment combinations. The irrigation treatments and data pertaining to them are listed as follows:

Treatment Designation and Irrigation Schedule	Irrigation Date 1961	Quantity of Water Applied, in.
A. No irrigation	--	--
B. One irrigation when moisture at 2-foot depth reached 23% (about 1 bar)	August 10	2.43
C. Irrigation everytime moisture at 2-foot depth reached 23% (about 1 bar)	August 10	2.16
	September 1	1.92
		4.08
D. Irrigation every two weeks	July 6	2.03
	July 19	1.65
	August 2	1.70
	August 16	1.74
	September 1	1.78
		8.90

The amount of irrigation water applied to the plots was measured with a calibrated Sparling meter. The 23 percent moisture content was selected on the basis that this would be about 1 bar of moisture potential of the soil water. It was originally planned to apply 4 to 5 inches of water per irrigation but this was not attained in the field plots. Measurements were not made of the water applied for the 1960 experiment but it is estimated that 20 to 25 inches were used.

Sorghum (RS-610) was planted on June 22 and June 28 after a preplant irrigation on June 16. The planting dates were different because the 1080 radioisotope injections could not be completed in one day.

The P^{32} solution was injected on June 28 and July 3. The sorghum seedling was just emerging from the seed bed at this time. Injections were made at 6 depth and 3 distance combinations. The 6 depths were at 6, 12, 24, 36, 48, and 60 inches from the soil surface and the horizontal distances were at 0 (in plant row), 10 and 20 inches from the plant row. In comparison the 1960 experiment had 6-, 12-, 18-, 24-, 36-, and 48-inch depths and 5-, 10-, 15-, and 20-inch distances. Six injections of 1 ml 14 μc/ml carrier-free KH_2PO_4 solutions were applied on the 10- and 20-inch distances and three injections for the treatment in the plant row. Construction details of the injection probes are described in the 1960 annual report.

Twelve 2-inch aluminum access tubes, one in each replicate, were installed 20 inches from the plant row for moisture measurements by the neutron probe method. Soil moisture was determined once a week at the 12-, 18-, 24-, 30-, 36-, 42-, 48-, 54-, and 60-inch depths starting on July 3.

Precipitation data (in inches) for the duration of the experiment are as follows:

July 3	0.16	:	August 4	0.01	:	September	0.02
July 4	0.17	:	August 11	0.04	:		
July 23	0.03	:	August 15	0.22	:		
July 29	0.55	:	August 18	0.54	:		
		:	August 23	0.24	:		
		:	August 24	0.04	:		
		:	August 29	0.80	:		
		:	August 30	0.05	:		
	0.91			1.94			0.02

Total = 2.87 inches

Weekly plant samples for P^{32} analysis were taken, starting July 7, of the sorghum planted on June 22 and, starting July 10, for those planted on June 28. The P^{32} activity was measured with thin-window gas flow counters on samples that were prepared using the $Mg(NO_3)_2$ dry-ash technique. An automatic sample changer was utilized to assay the 200 plant samples collected per week. It was necessary to design and construct a special relay-junction box (Figure 1) to operate the Nuclear-Chicago Model C-110B automatic sample changer through our existing Baird-Atomic Model 745A liquid scintillation counting system.

RESULTS AND DISCUSSION:

Root Growth and Distribution. The rate of root growth was found to be between 1.0 to 1.5 inches per day in all the treatments. Similar rates were obtained for the well-irrigated crop of the 1960 experiment.

The growth rate was obtained from data which indicated the time necessary for the appearance of P^{32} activity for a given tracer injection position. Lateral extension of the roots from the row was 30 inches and depth of penetration was at least 60 inches in the mature plants.

Relative Root Activity. The relative root activities in relation to soil depth and time are presented in Figures 2, 3, 4, and 5 for treatments A, B, C, and D, respectively; the plot for the 1960 investigation is given in Figure 6. The isometric plot was used to show the changes in the relative activity with time for each depth and also the relation of the relative activities in the profile for a particular sampling date. This relative root activity is the ratio of the quantity of P^{32} in a given position to the sum of the P^{32} in the whole injection profile. Because of possible unequal distribution of absorbed phosphorus in the plant with the age of the plant it is better to use the ratios of the specific activities $P^{32}/(P^{31} + P^{32})$ in the plant leaf but it was found in the 1960 experiment that the phosphorus content $(P^{31} + P^{32})$ of the sorghum remained fairly constant at $0.26 \pm 0.06\%$ (see Figure 7) and it was assumed that this constancy will also hold for the low irrigation level. It was felt that the gain in accuracy obtained by using specific activities was not large enough in relation to the amount of work involved in determining the phosphorus content of the leaves.

There is little difference in the relative root activity distributions in the various treatments. The activity in the upper 6- and 12-inch levels is consistently higher in treatments C and D than in treatments A and B where activity is more prominent at the 12- and 24-inch levels. Most of the root activity occurs close to the plant; about 80 to 90 percent of the activity is confined in an area 36 inches in depth and 10 inches laterally on both sides of the plant row.

The grain yield was 25.0, 33.8, 46.9 and 74.4 grams per head for treatments A, B, C, and D, respectively. The experiment, however, was not designed specifically for yields and thus the preceding figures can only be used as rough guides.

Soil Moisture Distribution. The moisture content in the soil profile as a function of time is presented for treatments A and B, and C and D, in Figures 8 and 9, respectively. Although measurements at 6-inch depth intervals were made, only the 12-inch intervals are reported to aid in following the moisture curves. Precipitation (P) of 0.15-inch or larger and irrigation (I) dates are also noted on the graphs. It is apparent that infiltration from rain and the small irrigation amounts did not extend beyond the 36-inch depth. Moisture depletion in the 5-foot profile within the 12-week sampling period was 3.5, 4.6, 2.6, and 3.0 inches for treatments A, B, C, and D, respectively, and if the quantity of water from precipitation and irrigation is added to the preceding values, these will become 6.4, 10.0, 10.3, and 14.8 inches. The soil profile at the time of planting contained 16.0 inches of water to the 5-foot depth.

The moisture characteristics of the soil are presented in Figure 10. Since this was determined on disturbed samples there is some error in the region less than 1 bar. If the wilting percentage is taken at 14.0 percent or 15 bar, it should be noted that the moisture content in treatment A where no irrigation was applied did not reach this moisture level. In treatment B, with one irrigation, however, the moisture content in the 12-inch depth got down to 13.5 percent. In treatment B also, the moisture content at the 12-inch level dropped from a value of 27.5 percent after irrigation to 13.5 percent in 4 weeks while that in treatment A changed from 19.0 to 14.8 percent.

Moisture Extraction and Root Activity Relation. The relative root activity and the percentage of moisture depleted from the surface 3 feet in respect to the total for the surface 5 feet are compared in Table 1 for treatment A. For the calculation of the percent of moisture lost, the amount of precipitation was taken into account. The data from the moisture distribution profile (Figure 8, A) indicates that none of the precipitation infiltrated below the 3-foot depth and thus the precipitation can be considered as part of the moisture of the upper 3-foot level.

The comparison shows a good relation between the relative root activity measured with the P^{32} tracer technique and the degree of moisture depletion determined with the neutron moisture probe. The water depletion percentages are consistently lower than the relative root activity values. Several possible explanations for this behavior exist and are being considered. The results, however, indicate that P^{32} and water absorption by roots are occurring at the same place in the soil profile.

SUMMARY AND CONCLUSIONS:

Relative root activity measurements were made on sorghum plants that were subjected to higher moisture stresses than that ordinarily encountered in an irrigated field of this area. The technique involved the determination of radioactive phosphorus-32 in the plant leaf after the radiotracer had been injected into the soil at varying distances from the plant.

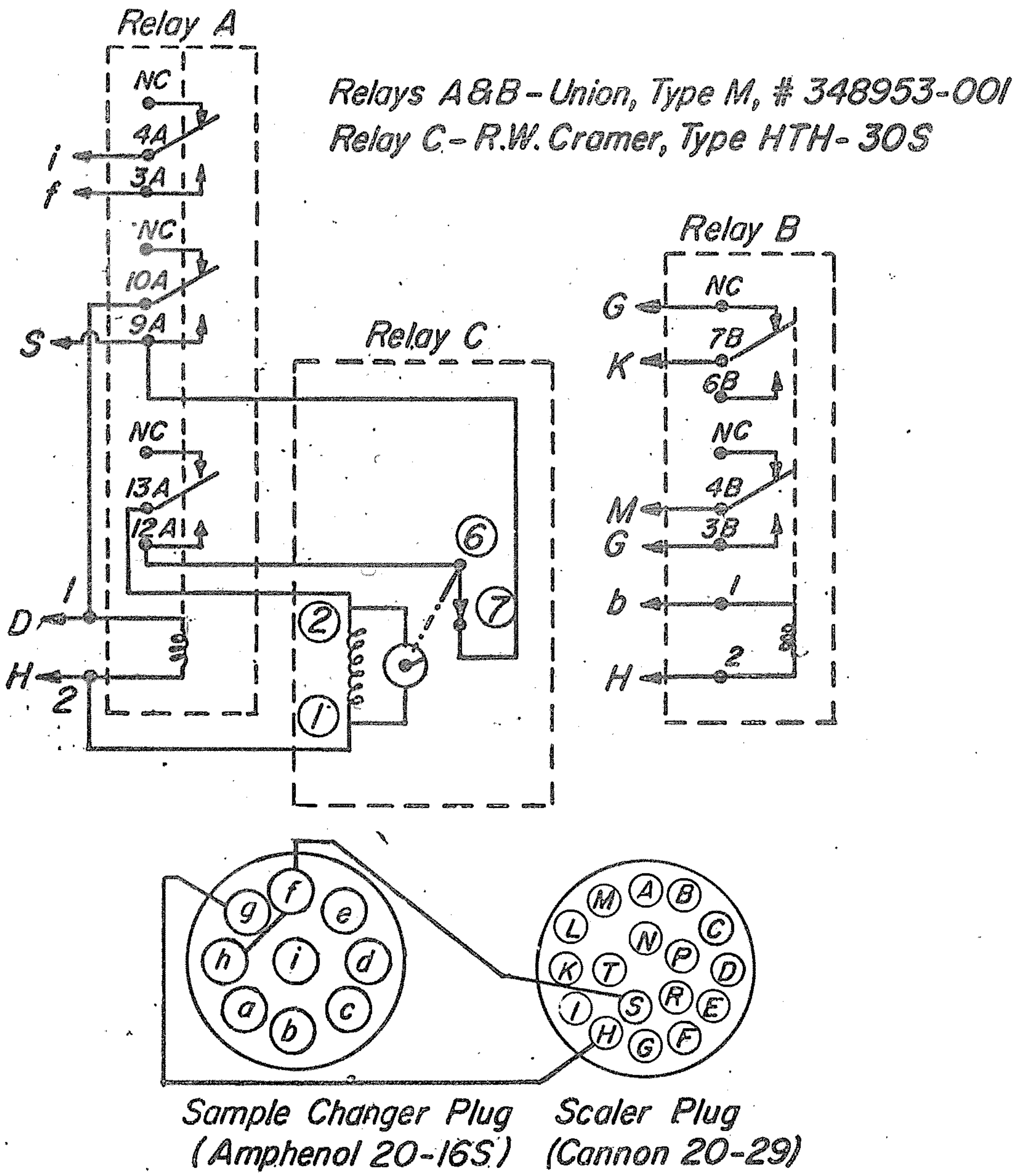
The data show that the rate of root growth is about 1 to 1.5 inches per day and the root extension is 30 inches laterally and at least 60 inches vertically from the plant row. Relative root activity distribution patterns were similar for all the irrigation levels investigated. Approximately 90 percent of the root activity is in the 10-inch lateral and 36-inch vertical distances from the plant.

The relative root activity distribution is related closely to the moisture depletion patterns in the surface three feet as measured with the neutron moisture probe. It is thus evident that nutrient and water absorption for this crop occurs concurrently and to a large extent above the 3-foot depth.

PERSONNEL: F. S. Nakayama, C. H. M. van Bavel.

Table 1. Relative root activity and moisture depletion in the surface 3 feet of the soil profile for treatment A.

Date 1961	Root Activity, % of Total	Water Depletion % of Total
7/17	97.1	92.7
7/24	90.6	85.1
7/31	95.1	88.3
8/ 7	96.8	82.0
8/14	97.0	83.2
8/21	96.7	83.5
8/28	93.8	85.2
9/ 4	90.3	88.0
9/11	89.5	85.8
9/18	80.0	85.3



Modification in B-A Scaler

1. Connect contact 4, K101 relay to J101 pin D
2. Connect S102A to J101 pin S

Modification in N-C Sampler Changer

1. Short SW 1A Auto to time
2. Connect pin H to pin F

Modification in N-C Print Timer

1. Connect pin B to pin F

Figure 1. Schematic diagram of relay-junction box to operate Nuclear-Chicago Model C-110B automatic sample changer with the Baird-Atomic Model 745A liquid scintillation counting system.

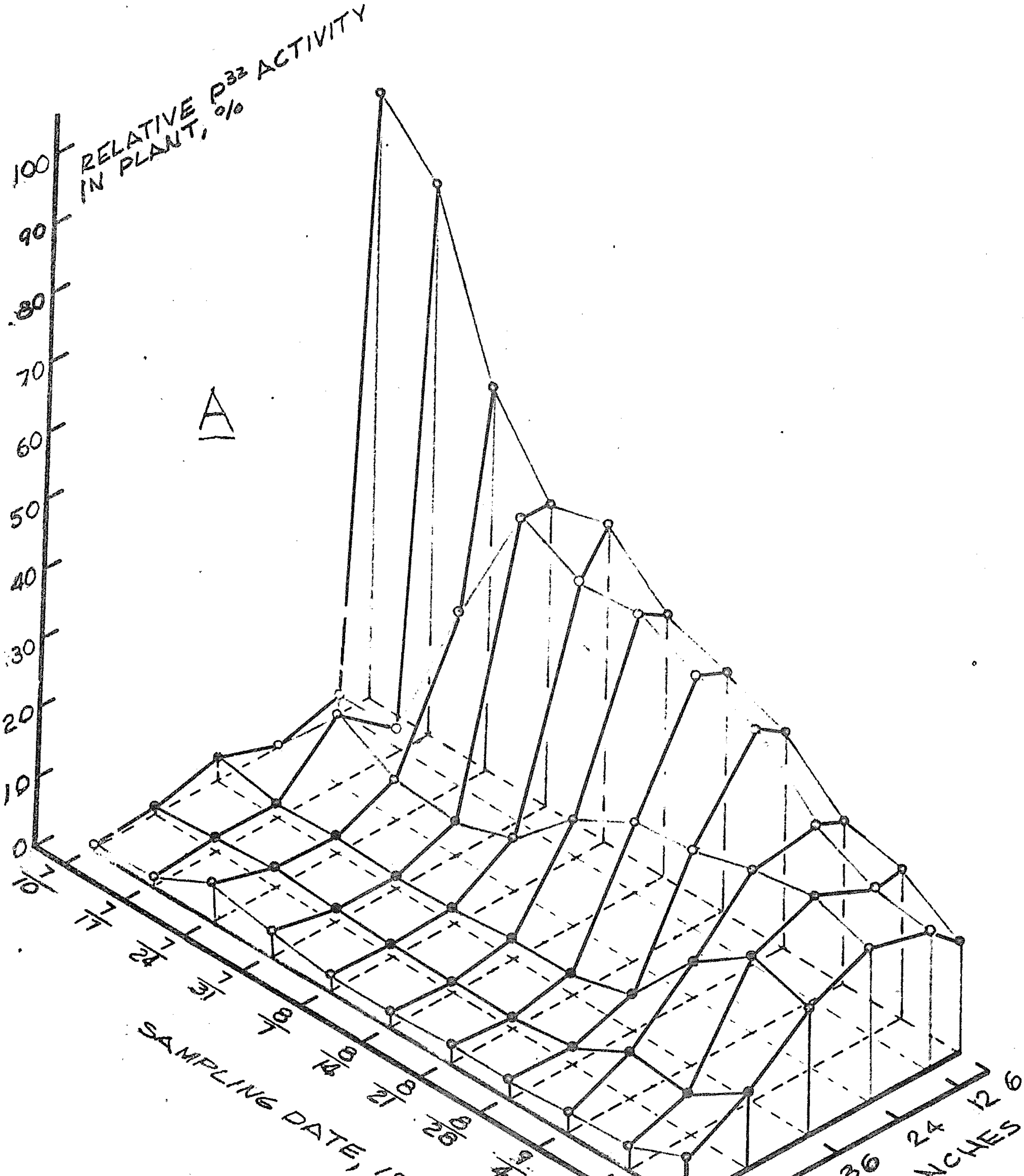


Figure 2. Relative root activity as a function of depth and time for treatment A.

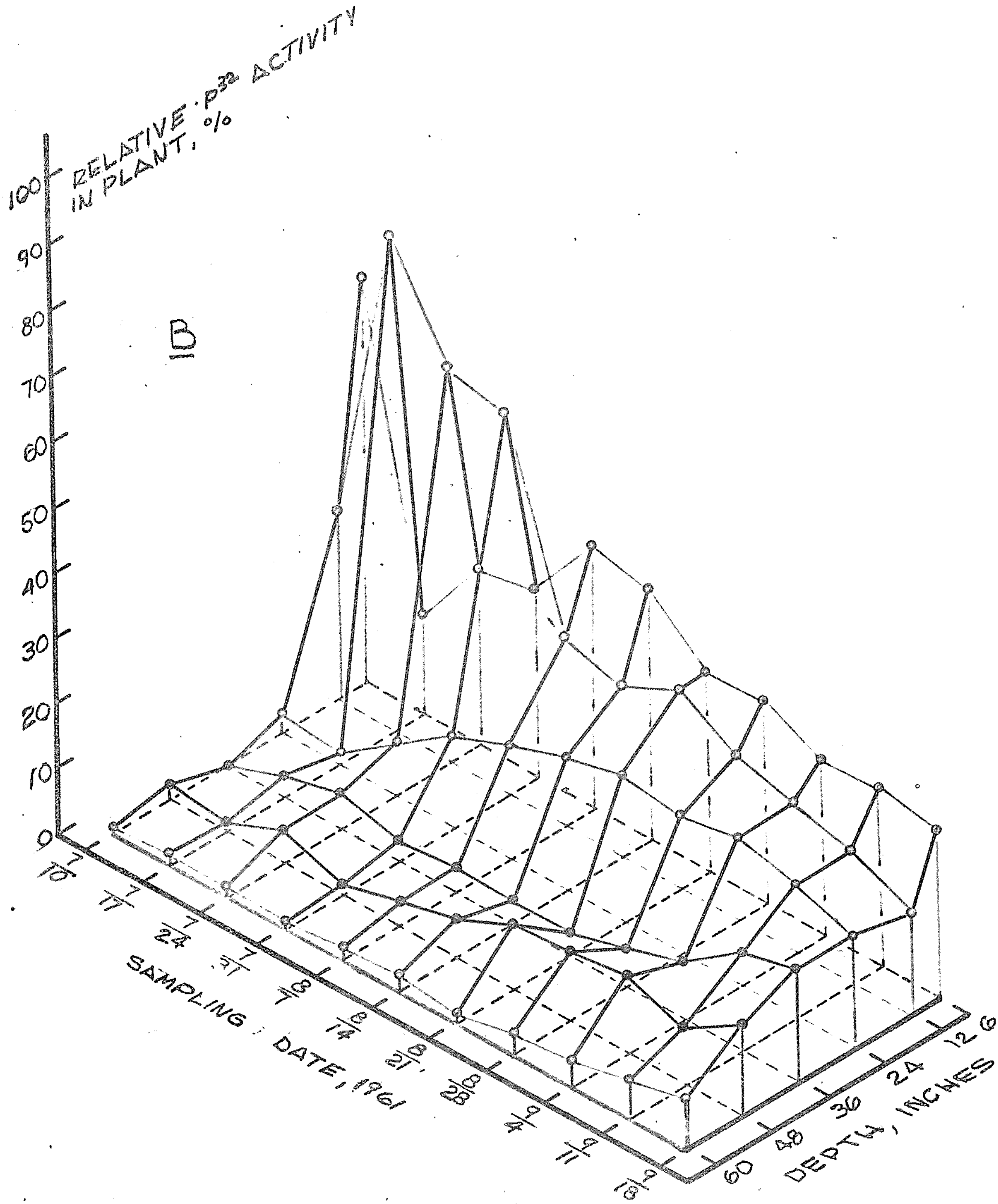


Figure 3. Relative root activity as a function of depth and time for treatment B.

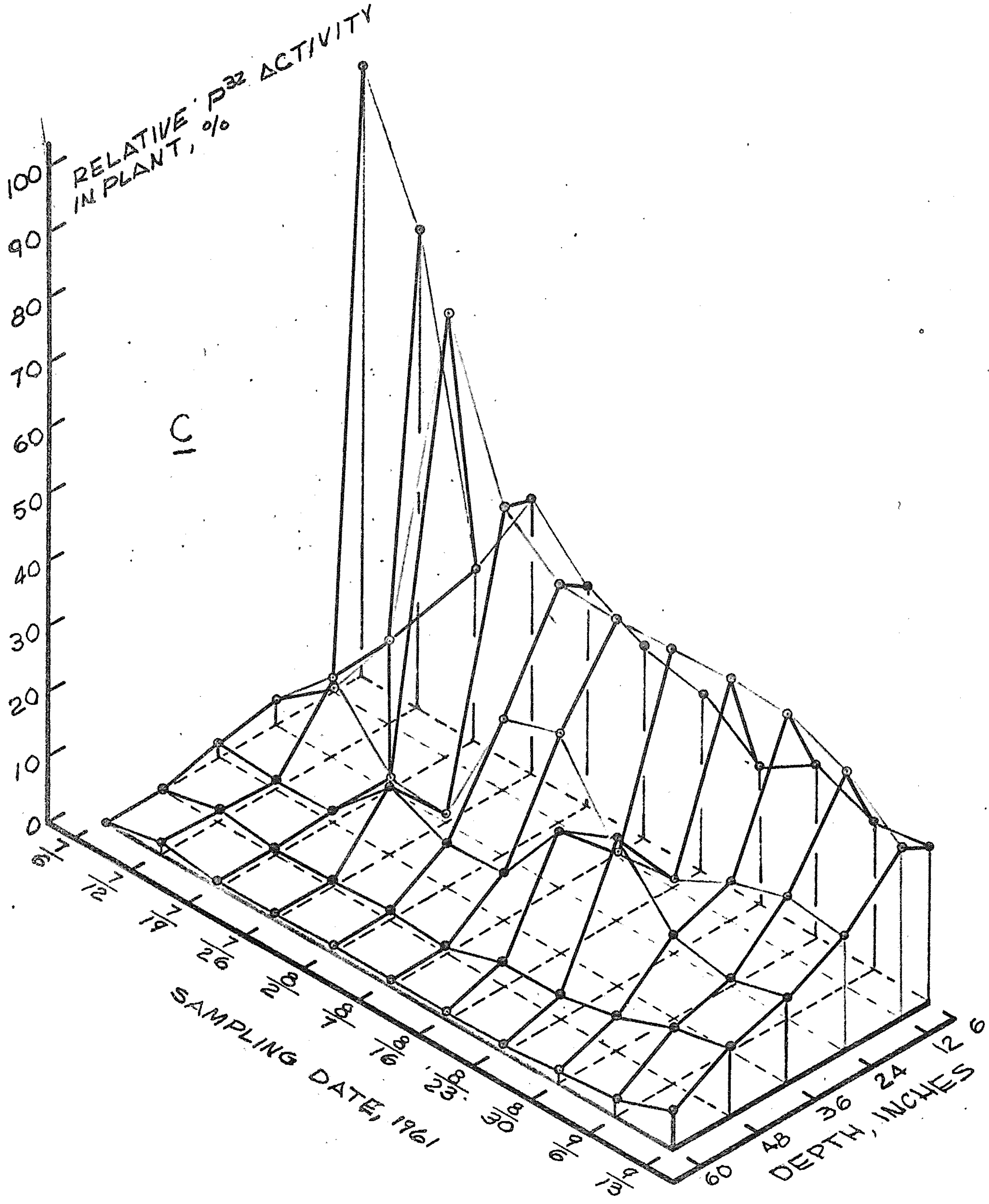


Figure 4. Relative root activity as a function of depth and time for treatment C.

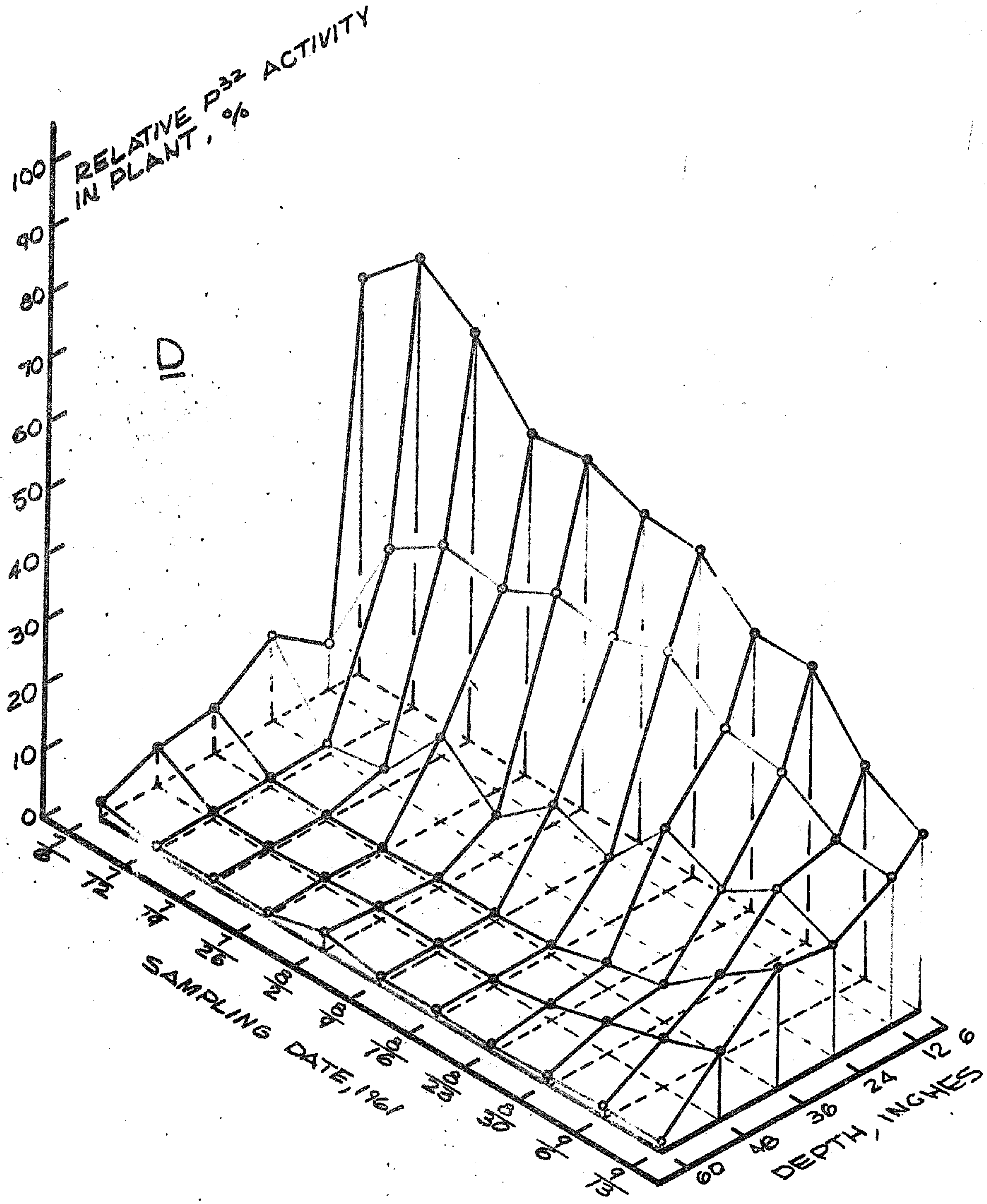


Figure 5. Relative root activity as a function of depth and time for treatment D.

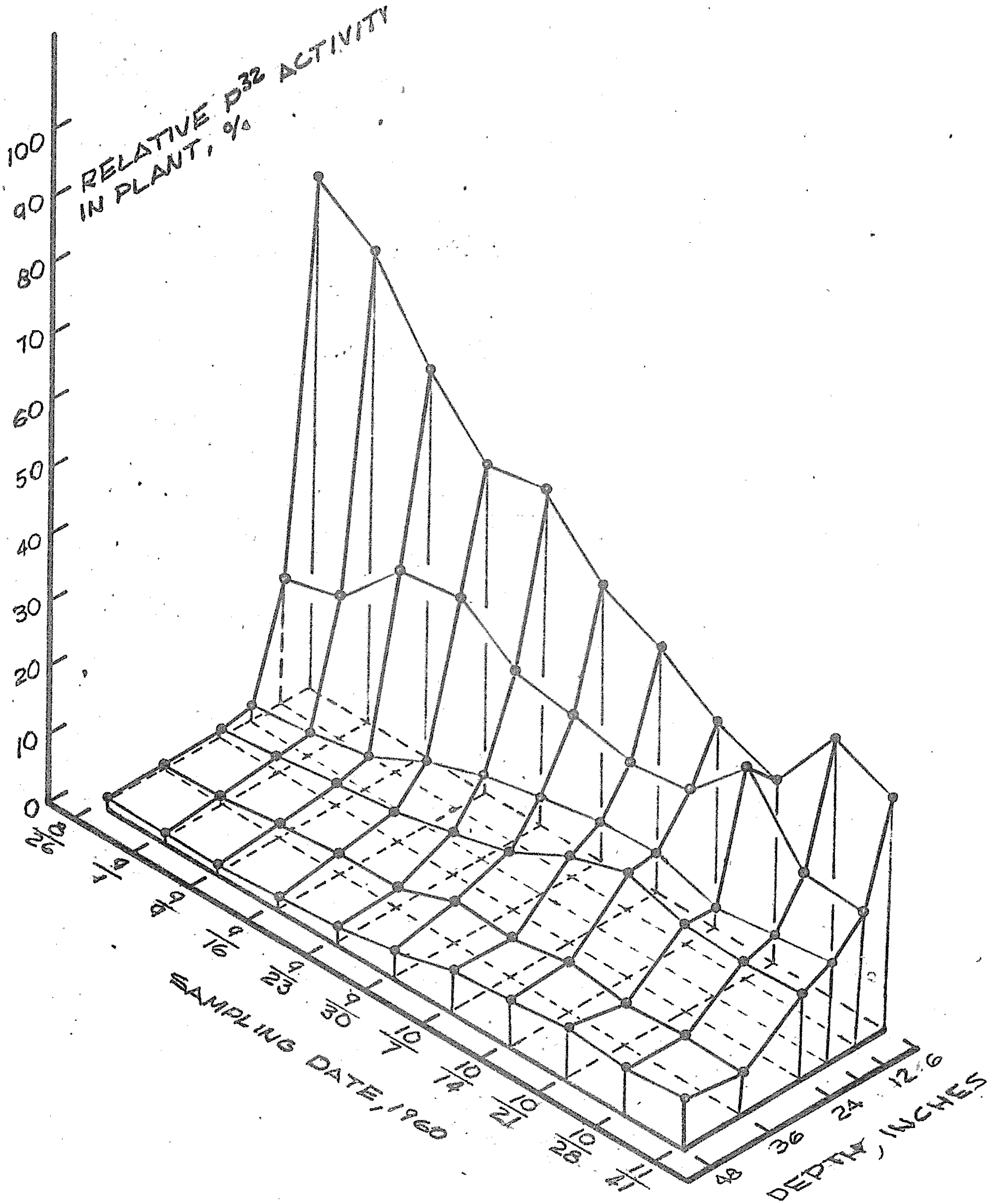


Figure 6. Relative root activity as a function of soil depth and time for experiment conducted in 1960.

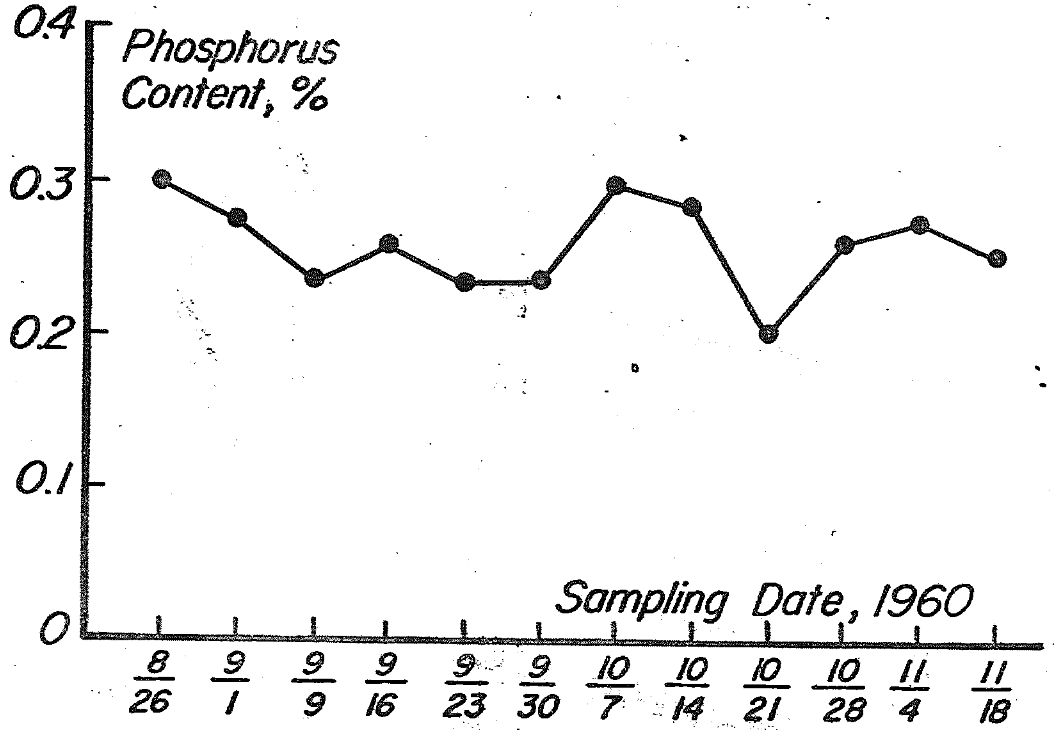
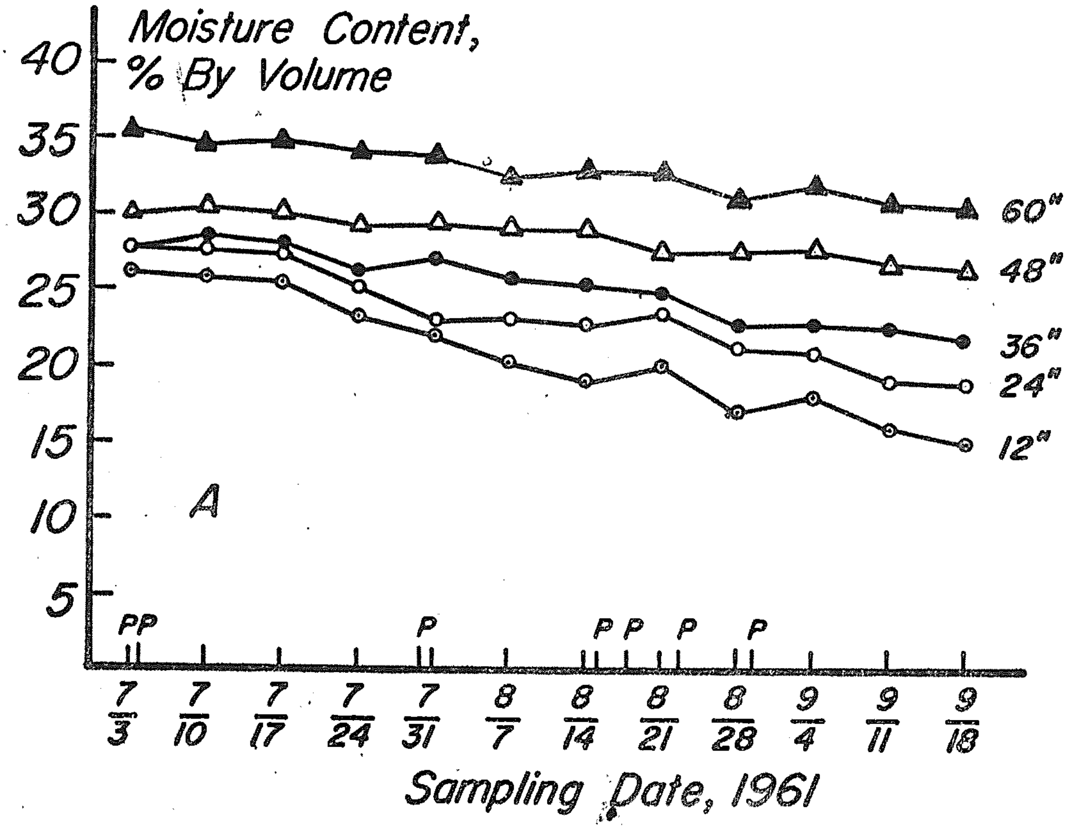


Figure 7. Phosphorus content of sorghum leaves.



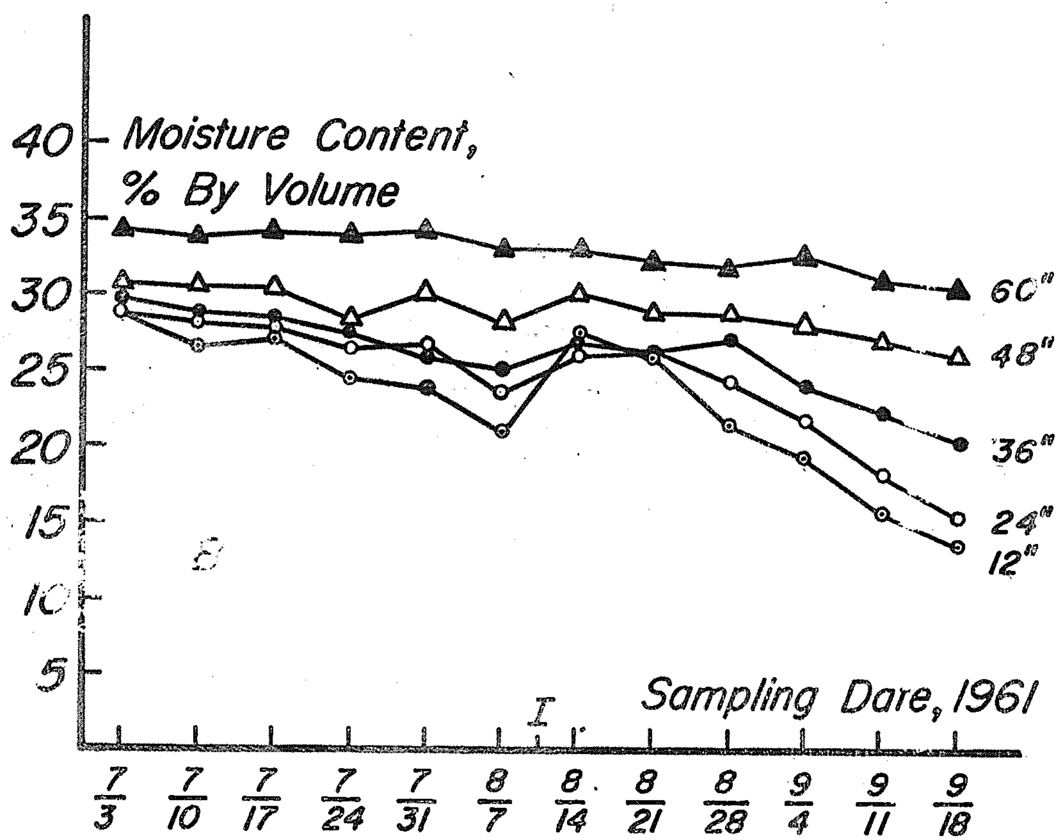


Figure 8. Moisture content in the soil profile (treatments A and B).

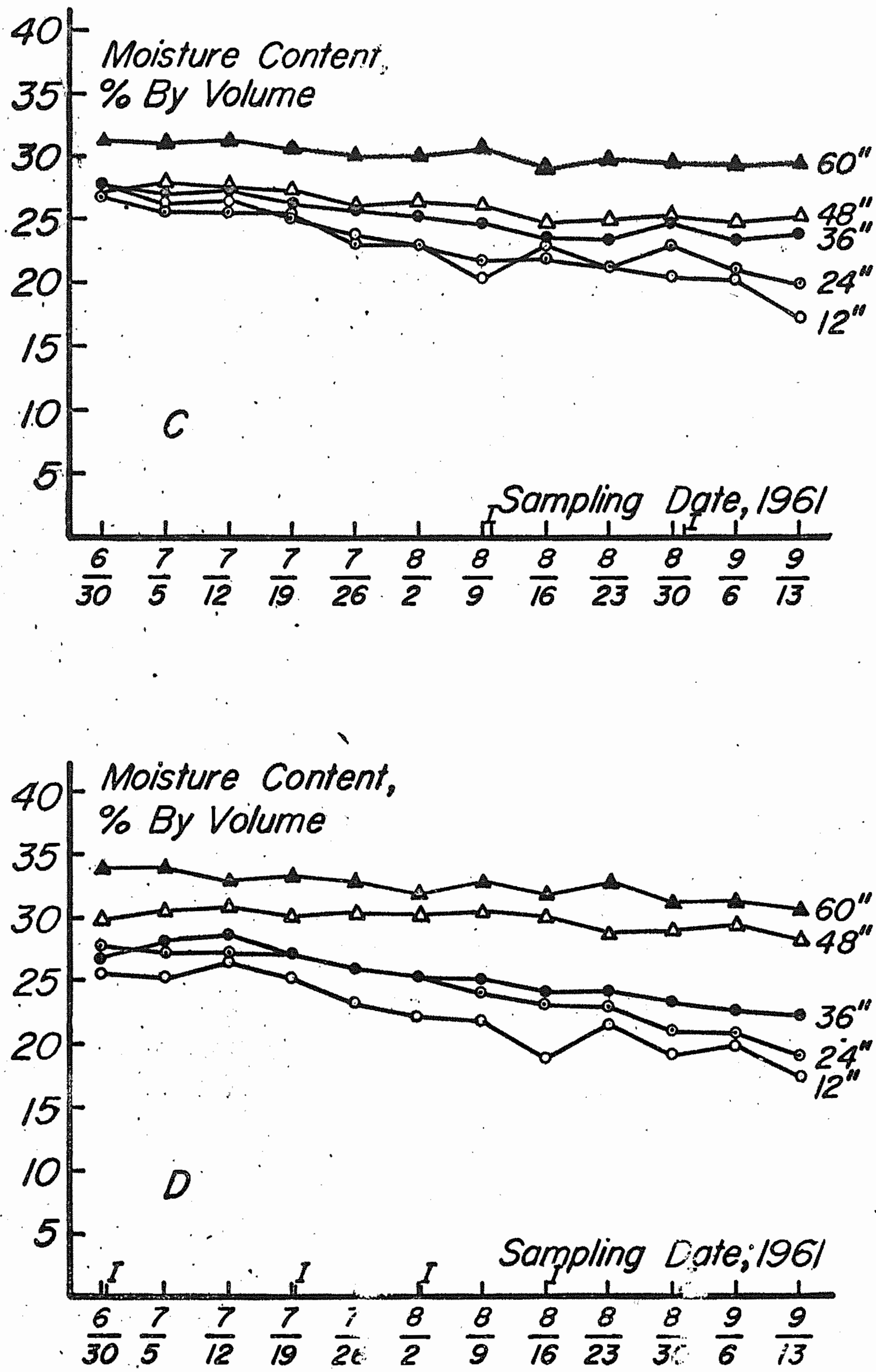


Figure 9. Moisture content in the soil profile (treatments C and D).

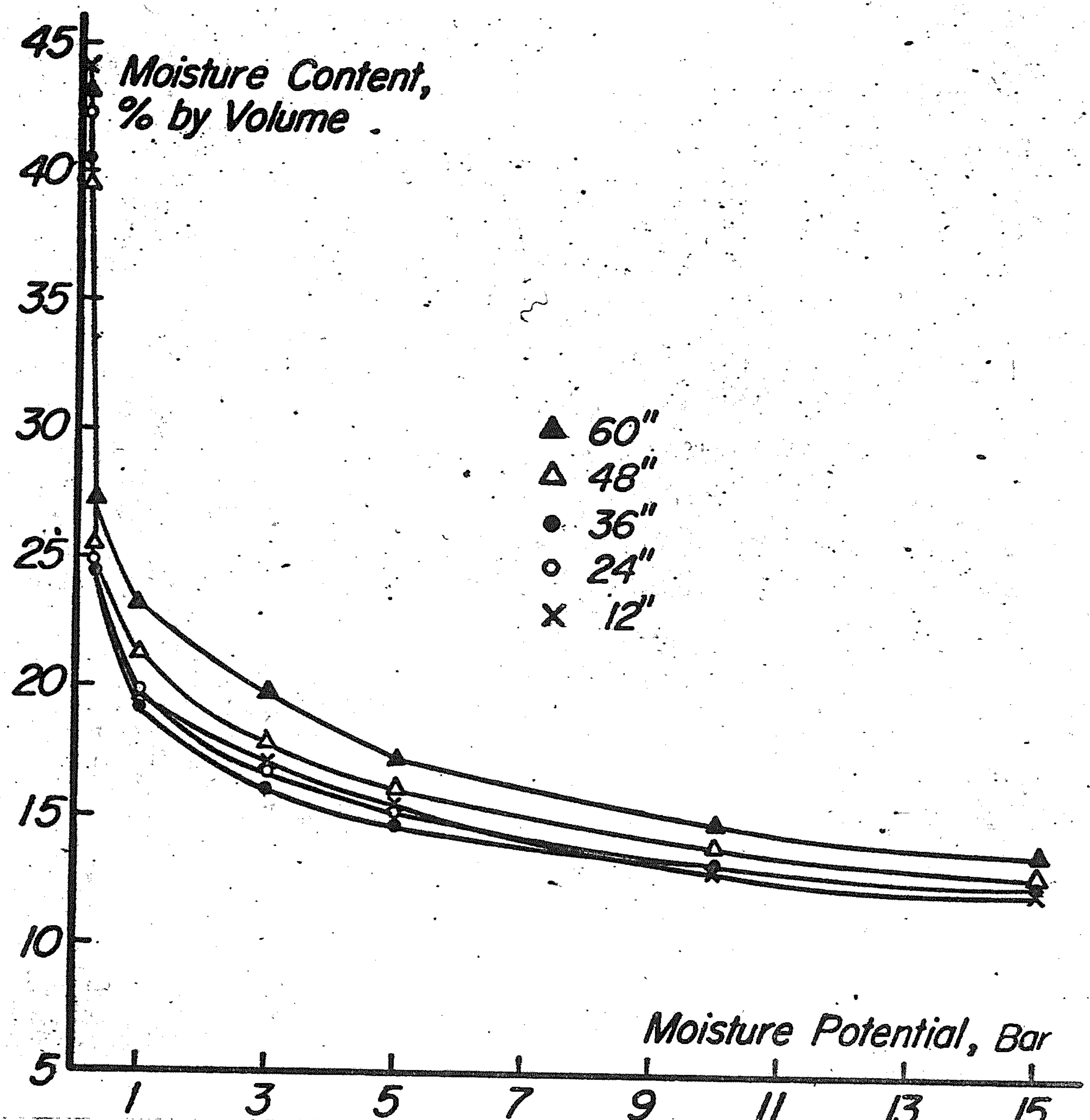


Figure 10. Moisture characteristic for Laveen loam.

TITLE: SOIL MOISTURE POTENTIALS AND WATER UPTAKE BY ROOTS

LINE PROJECT: SWC 11-gG1 CODE NO.: Ariz.-WCL-3

INTRODUCTION:

The objectives of this research project have been stated on page 72 of the Annual Report for 1960.

An important aspect that had to be considered in the use of tritiated water (THO) as a tracer to study water uptake by plant roots from moist soils is the movement of the tracer in the soil medium irrespective of the actual water absorption and consequent transloca-tion processes in the plant. For example, if a radioactive tracer source is placed near an absorbing root surface, the increase in radioactivity in the plant or the decrease in activity of the tracer source is not only the result of absorption of the tracer by the plant, but also the result of the diffusion of tracer away from the source to its surroundings. Experiments were thus conducted to define more clearly the diffusive property of THO in soil and to evaluate it in terms of the main objectives of this project.

METHOD:

The method for determining the diffusion coefficient involves placing a plane source of tracer instantaneously at one end of a long soil column. The equation which describes the concentration of tracer at any distance and time is [Barrer, 1],

$$\partial c/\partial t = D\ \partial^2 c/\partial x^2 \quad , \qquad [1]$$

where c = concentration of tracer,

t = time,

D = diffusion coefficient - a constant,

x = distance.

If the medium is sufficiently long and the time during which the diffusion proceeds is sufficiently short so the concentration does not change at the finite boundary, then the column can be assumed infinite in length and a solution of [1] applicable to this problem is (Barrer, 1, p. 45)

$$c = Q\ (\pi Dt)^{-1/2} \exp\ [-x^2/(4Dt)] \quad , \qquad [2]$$

where Q is the quantity deposited at the plane x = 0.

Equation [2] assumes a homogeneous medium of uniform cross section. If the soil columns meet these conditions then the activity of the diffusing tracer is directly proportional to the concentration and equation [2] can be written as

$$A = A_o\ (\pi Dt)^{-1/2} \exp\ [-x^2/(4Dt)] \qquad [3]$$

where A = the activity per unit volume,

A_o = the total activity deposited at the plane x = 0.

Rearranging, equation [3] becomes

$$\ln A/A_o = -\frac{1}{2} \ln\ (\pi Dt) - x^2/(4Dt) \quad . \qquad [4]$$

A plot of $\ln A/A_o$ versus x^2 yields a curve with a slope of $-\frac{1}{4Dt}$ and and intercept of $-\frac{1}{2} \ln$ (Dt) from which the diffusion coefficient may be calculated. Equation [3] may be integrated to allow an analytical calculation of D. The result is

$$A_x/A_o = \text{erf}\ x/(4Dt)^{1/2} \quad , \qquad [5]$$

where A_x is the activity in the column over the distance x = 0 to x = x, A_o, x, D, t are as defined previously. The notation erf is the error function whose values are tabulated in mathematical handbooks (4).

PROCEDURE:

The diffusion coefficient of tritiated water (D_{THO}) was determined in agar gel, moist glass beads and soils in specially constructed cylindrical diffusion columns. The variable-length column was made by taping together appropriate numbers of lucite rings (1 cm long × 1.9 cm I.D. and also 1 cm long × 3.2 cm I.D.) which were machined from 1 1/4-inch and 1 1/2-inch lucite tubings.

Agar solution was prepared by dissolving agar powder in distilled water in a steam sterilizer. The hot solution was poured into the 1.9 cm I.D. diffusion column and allowed to cool slowly to room temperature to form the gel. Special care was taken to prevent entrapment of air in the column.

The air-dry soils (Adelanto, Colo, Fort Collins, and Pachappa) and glass beads (28 and 203 μ) were packed in 3.2 cm I.D. diffusion columns with a mechanical column packer (2) to obtain uniform packing throughout the column. The mechanical analysis of the soils is presented in Table 1. To obtain moisture contents in the materials above 35% by volume, the soil or glass bead columns were wetted using a fritted glass bead plate as a water source at -2 mb pressure potential. The 9 to 34% moisture columns were prepared by placing the columns containing the air-dry material upon a ceramic plate in a pressure cooker apparatus, saturating with distilled water and then applying pressure to the system to desaturate the soil to the desired moisture contents. For materials at moisture contents less than 9%, except air-dry soil, the unconsolidated soil was saturated and desaturated on the pressure membrane apparatus; the soil was then hand-packed into the diffusion column.

One end of the packed column was fitted with a filter paper disk. A 0.01 ml sample of 100 μc/ml THO solution was spread on the filter paper and the column sealed with tape and stored at 25 ± 2 C. After a given contact period between the tracer source and the medium, 1 to 20 days, the entire column was dismantled into 1 cm or longer sections.

Before the activity of the tracer water in the sections could be analyzed, the water had to be separated from the medium. Extraction of the water, therefore was made using a modified lyophilization technique. The sample flask was connected to ~~the moisture~~ extraction apparatus (see Figure 1) and the system was evacuated. The THO-H_2O vapor was condensed in an easily detachable cold-finger trap at approximately -72°C using a solid CO_2-alcohol bath. To speed the extraction process, the sample was heated with an infrared lamp.

An aliquot (0.25 to 1.0 ml) of the extracted water was transferred into 15 ml of liquid scintillation counting solution. The THO activity was analyzed on the Baird-Atomic liquid scintillation system. Analytical procedures and instrumentation is described on pages 73 to 76 of the 1960 Annual Report for this Laboratory.

RESULTS AND DISCUSSION:

Typical data for the diffusion measurements are plotted in Figure 2 for an agar gel and a Pachappa soil. The experimental points lie on a straight line and it is apparent that the experimental procedures satisfy the conditions that were imposed in the derivation of equation [3]. The D_{THO}'s calculated from the graphical and analytical methods are essentially the same. Because of the simpler operations involved in the calculation of the diffusion coefficients using the error function tables, the analytical method was used in preference to the graphical technique.

The D_{THO}'s in agar gel and moist glass beads are presented in Table 2. The gel was used because this is a medium in which the water is very similar to liquid water, yet easily handled. The average D_{THO} for the three different agar compositions is 2.16×10^{-5} cm^2/sec and compares to that of 2.44×10^{-5} cm^2/sec determined by Wang, et al. (5) in liquid water. He also reports the diffusion coefficient of deuterated water (DHO) as 2.34×10^{-5} cm^2/sec which is smaller than that for tritiated water. It would be expected that D_{DHO} should be greater than D_{THO} on the basis that diffusion is a function of the molecular weight, but the experimental results show the reverse. The cause for this discrepancy has not been resolved.

The D_{THO} in moist glass beads (Table 2) was lower than that in agar gel. Kunze and Kirkham (3) reported a D_{DHO} value of 1.36×10^{-5} cm^2/sec for moist glass beads compared to our D_{THO} of 1.56 and 1.69×10^{-5} cm^2/sec.

Experimental data for the moist soils are listed in Table 3. The D_{THO} in Colo clay loam is 0.87×10^{-5} cm^2/sec. A D_{DHO} value of 0.61×10^{-5} cm^2/sec is reported by Kunze and Kirkham (3).

Since it is contemplated to follow water absorption by roots at different moisture potentials, a more rigorous study was made on the relation between the moisture content and the diffusion coefficient of

THO. The results of these investigations are presented in Figure 3 for the Pachappa soil. It is apparent from the graph that D_{THO} is not the same for the different moisture contents of the soil. However, in the moisture region between 10 to 40 percent where most of the water absorption studies will be conducted, the D_{THO} is constant and thus facilitates comparison of the results of water uptake by roots for samples of slightly different water content. The average diffusion coefficient between 34 to 39 percent water content is $1.14 \pm 0.05 \times 10^{-5}$ cm^2/sec.

There are large variations in D_{THO} with moisture content between the 1.5 (air-dry) and 9 percent levels with a peak D_{THO} occurring at approximately 3 percent. Additional experimental data must be obtained to define more precisely the relationships observed over this particular region.

A possible explanation for the behavior observed can be presented more clearly by considering the moisture content-D_{THO} curve in its entirety. The D_{THO} is 1.14×10^{-5} cm^2/sec compared with that measured in agar gel of 2.16×10^{-5} cm^2/sec, which we assumed to be close to the true THO diffusion in liquid water. The D_{THO} in this particular soil-water system is smaller primarily because of physical blocking by the soil particles which lie in the diffusion path. With decreasing moisture and the voiding of the water-filled pores, diffusion occurs in the liquid and vapor phases. When the continuity of the air-filled pores is established below approximately 10 percent water content, vapor diffusion becomes predominant although liquid diffusion occurs in the surface water films.

It should be noted that the measured diffusion coefficient is many times smaller than the diffusion coefficient of water vapor in air, which is on the order of 0.24 cm^2/sec. At the place where D_{THO} is at a maximum, there is a minimum restraint to movement imposed upon the tracer molecule from the surface-layer water molecules on the soil particles, the soil particles, and possibly also, less exchange occurring between the tracer and the adsorbed molecules.

At the lower moisture content region from the D_{THO} peak, the THO molecules become adsorbed more readily either directly on the soil particle or on the untagged water molecules already present on the clay mineral surfaces and thus the adsorptive forces act to reduce the movement of the tracer.

SUMMARY AND CONCLUSIONS:

The diffusion coefficient of tritiated tracer water was determined in agar gel and moist soils and glass beads preliminary to studies of water absorption of plant roots in soils. The experimental results for the homogeneous materials agreed closely with the theoretical diffusion equation. The diffusion coefficient of tritiated water (D_{THO}) in dilute agar gel is 2.16×10^{-5} cm^2/sec and in the moist glass beads is 1.56 and 1.69×10^{-5} cm^2/sec at 35.9 and 17.8 percent water content, respectively; and the D_{THO} for soils is on the order of 1.0×10^{-5} cm^2/sec.

In a Pachappa loam soil in which the D_{THO} was investigated more thoroughly, the D_{THO} was found to be a function of the amount of water in the soil. The diffusion coefficient is essentially constant at 1.14×10^{-5} cm^2/sec between 12 and 40 percent moisture content, has a maximum value of about 4.0×10^{-5} cm^2/sec at approximately 3.5 percent and has intermediate values between 1.5 (air-dry) to 3.5, and 3.5 to 10.0 percent moisture contents. The results bring up some thought-provoking questions in regard to vapor and liquid diffusion in soils, soil-water properties and the use of tritium tracer in water movement studies in unsaturated soils.

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PERSONNEL: F. S. Nakayama, R. D. Jackson, and C. H. M. van Bavel (Advisory).

Table 1. Mechanical analysis of soils used in THO diffusion studies.

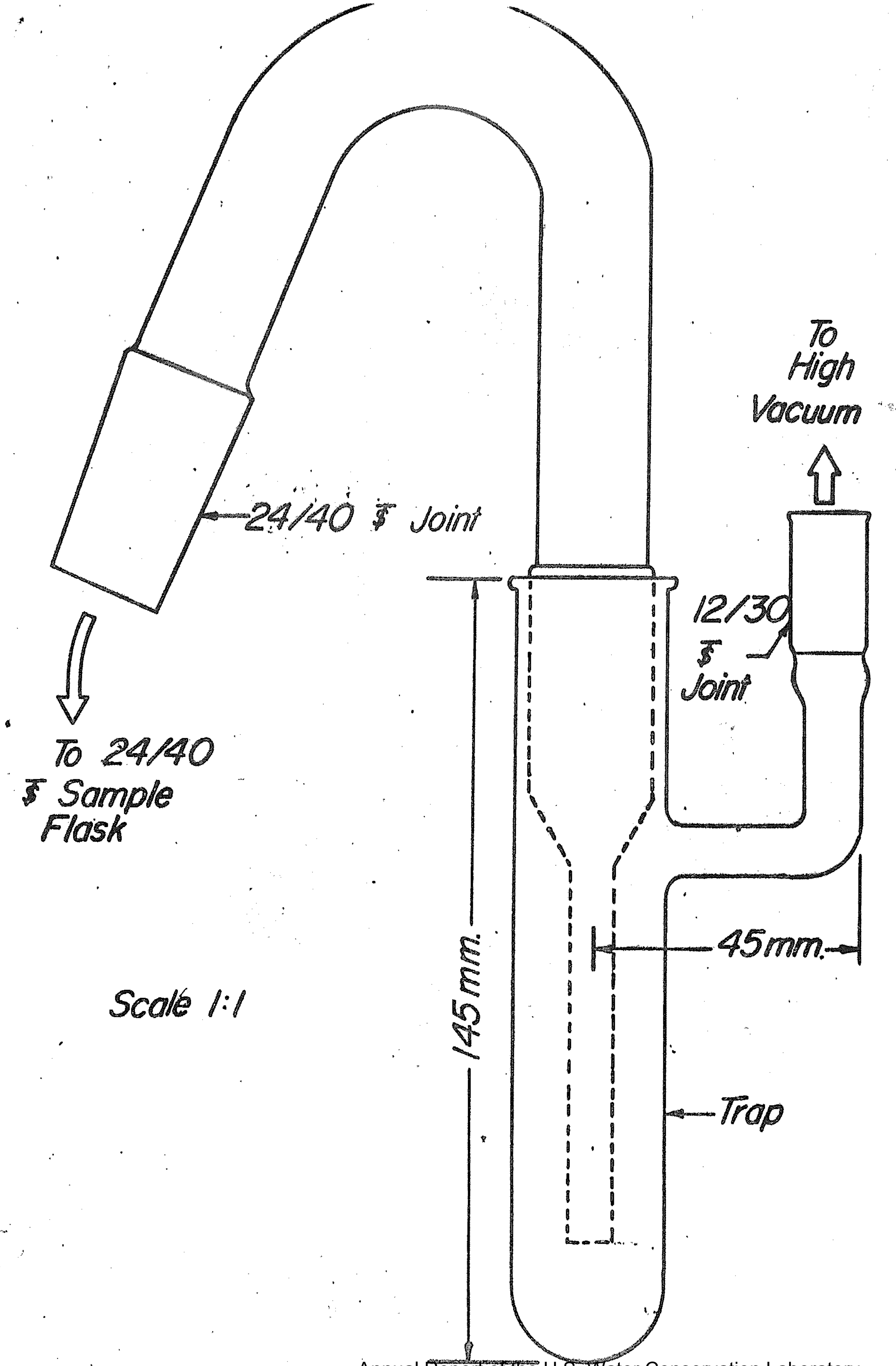
Sample	Sand (>50μ)	Coarse Silt (20-50μ)	Fine Silt (2-20μ)	Clay (<2μ)	Textural Class
Adelanto	31.56	24.24	21.85	22.35	Loam
Colo	21.88	13.62	31.95	32.55	Clay Loam
Fort Collins	40.55	19.95	16.00	23.50	Loam
Pachappa	41.60	36.59	13.30	8.50	Loam

Table 2. Diffusion coefficient of THO in agar gel and moist glass beads.

Material	Composition	Moisture Content, Percent by Volume	Diffusion Coefficient of THO, $cm^2/sec \times 10^5$
Agar gel	0.50 %	--	2.19
Agar gel	0.75 %	--	2.26
Agar gel	1.00 %	--	2.11
Glass beads	28 μ	35.9	1.56
Glass beads	28 μ	17.8	1.69
Glass beads	203 μ	34.9	1.68

Table 3. Diffusion coefficient of THO in moist soils.

Soil	Moisture Content, Percent by Volume	Diffusion Coefficient of THO, $cm^2/sec \times 10^5$
Adelanto Loam	38.5	1.01
Colo Clay Loam	33.7	0.87
Fort Collins Loam	36.8	1.08
Pachappa Loam	36.9	1.14


To High Vacuum
24/40 ₮ Joint
12/30 ₮ Joint
To 24/40 ₮ Sample Flask
145 mm.
45 mm.
Trap
Scale 1:1

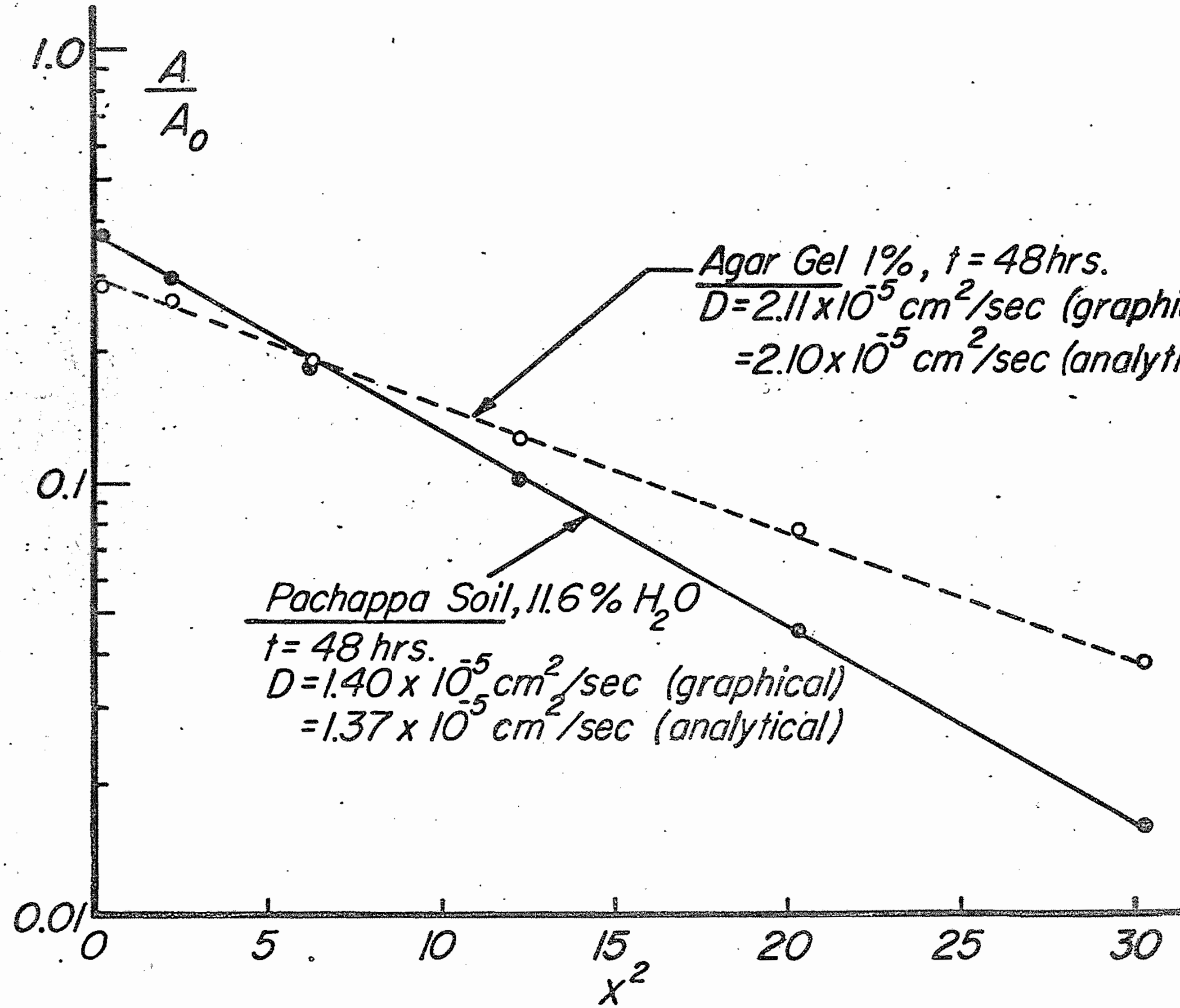


Figure 2. Typical plot of data showing activity of THO in diffusion column as a function of distance.

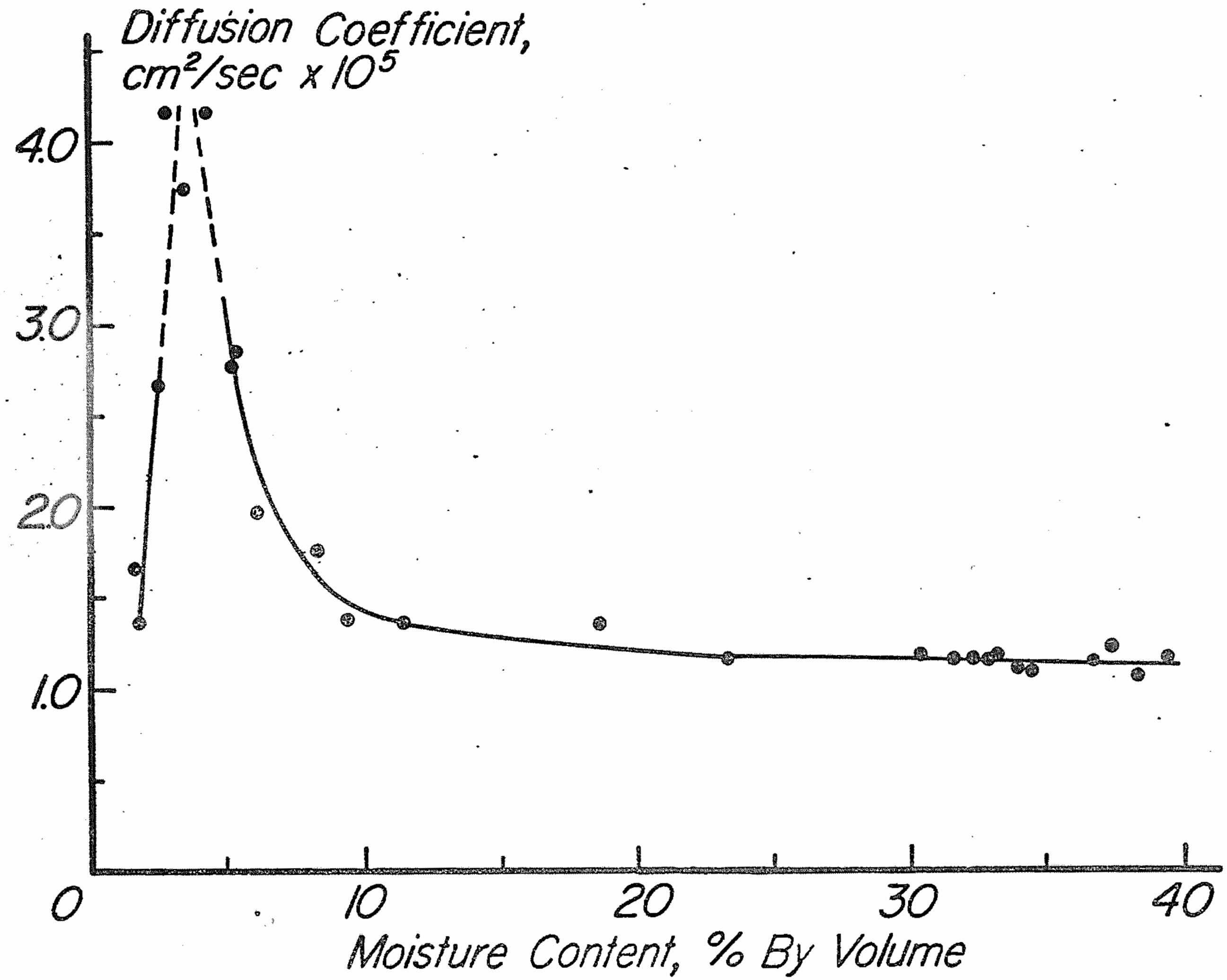


Figure 3. The diffusion coefficient of THO in Pachappa loam at different moisture contents.

TITLE: THE MEASUREMENT OF WATER TRANSPORT IN COMPLEX TUBES WITH SPECIFIC APPLICATION TO THE ASSESSMENT OF SOIL-WATER LOSSES BY TRANSPIRATION

LINE PROJECT: SWC 11-gG1 CODE: Ariz.-WCL-5

INTRODUCTION:

The objectives, need for study, and method of this project are given in the 1960 Annual Report of the U. S. Water Conservation Laboratory. In that report the mathematics of moving sources of heat was used to develop a mathematical model which describes, in the first approximation, heat flow in the sap stream of a plant when a portion of the sap is heated. This model is intended to facilitate the interpretation of data obtained by using a radio-frequency oscillator to heat a thin cross section of a plant essentially instantaneously and noting the temperature pulse at a known distance from the source. The purpose is to obtain a measurement of the velocity of the sap stream within the plant stem.

PROGRESS DURING 1961

The radio-frequency oscillator was delivered in August 1961. Subsequent to delivery it was necessary to design a tuning circuit to be used near a plant stem. This consisted of a variable inductor, two variable capacitors, and a pair of electrodes. The purpose of these components is to provide a means of obtaining resonance in the heating circuit. Different plant stems exhibit different dielectric properties and different sizes of plant stems require different electrode spacings and hence change the capacitance of the system. The resulting changes in dielectric properties are compensated by the variable capacitance and inductance in the tuning circuit, allowing resonance to be obtained. To obtain resonance adjustments are made strictly by trial.

The radio-frequency oscillator has a power output on the order of 20 watts at 108 megacycles. A schematic diagram of the oscillator is given in Figure 1. Figure 2 shows a schematic of the timing circuit and of the external tuning circuit.

Experimental results to date have been strictly qualitative in that the measurement was made on plants in order to check the oscillator and the tunings circuit. No estimate was made of the velocity of the sap stream or of the validity of the theoretical development given in the 1960 Annual Report.

When the circuit is tuned properly, portions of the plant stem can be heated in a very few seconds and this heat pulse can be measured at a distance further up the plant stem. The adjustment of the tuning circuit is strictly by trial and is frequently time consuming. Once tuned, however, the oscillator will provide sufficient heat to raise the temperature of the water inside a plant stem a measurable amount. It is possible to tune the circuit such that sufficient heat is produced within the plant to burn the bark. The problem remains to tune the circuit properly so that a sufficient amount of heat is produced within the plant stem that can be measured at a known distance downstream and yet not enough heat is produced to damage the plant itself. In one case when heat was applied to a bean plant, a dark blue ring formed immediately around the plant near the electrodes, indicating that the water within the plant was heated very rapidly and possibly caused damage to the plant. In practically all cases when plants were used, a heat pulse was detected.

In one experiment glass tubes within which water was flowing at a known velocity were used. This experiment was not successful in that thickness of the glass proved to be such an insulator that the water within the glass tube could not be heated a sufficient amount to measure temperature rise at a point downstream. In one case where rather large electrodes were used and a thermistor was placed inside of the glass tube in direct contact with the water, a heating pulse was detected.

PERSONNEL: R. D. Jackson, W. L. Ehrler, and F. S. Nakayama

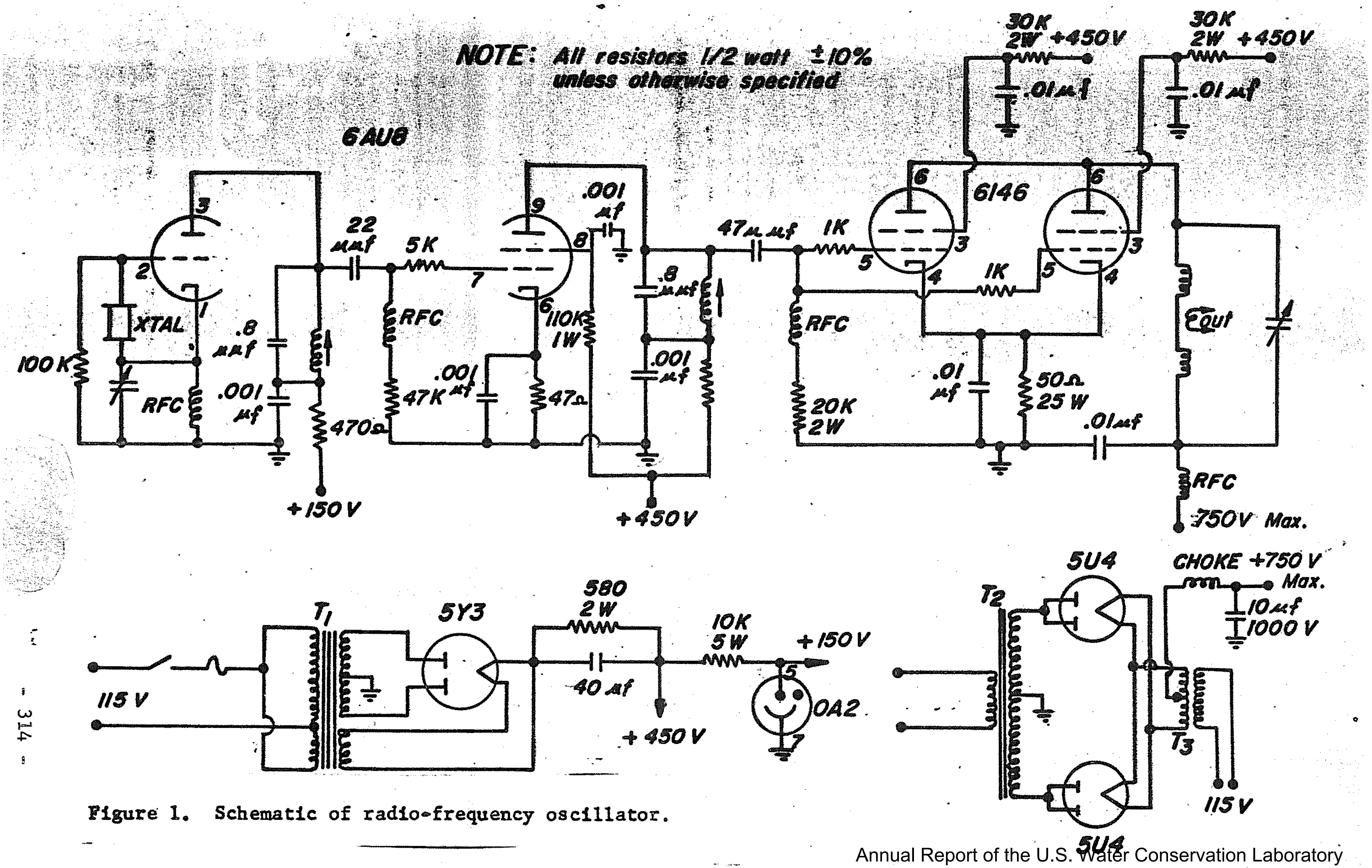


Figure 1. Schematic of radio-frequency oscillator.

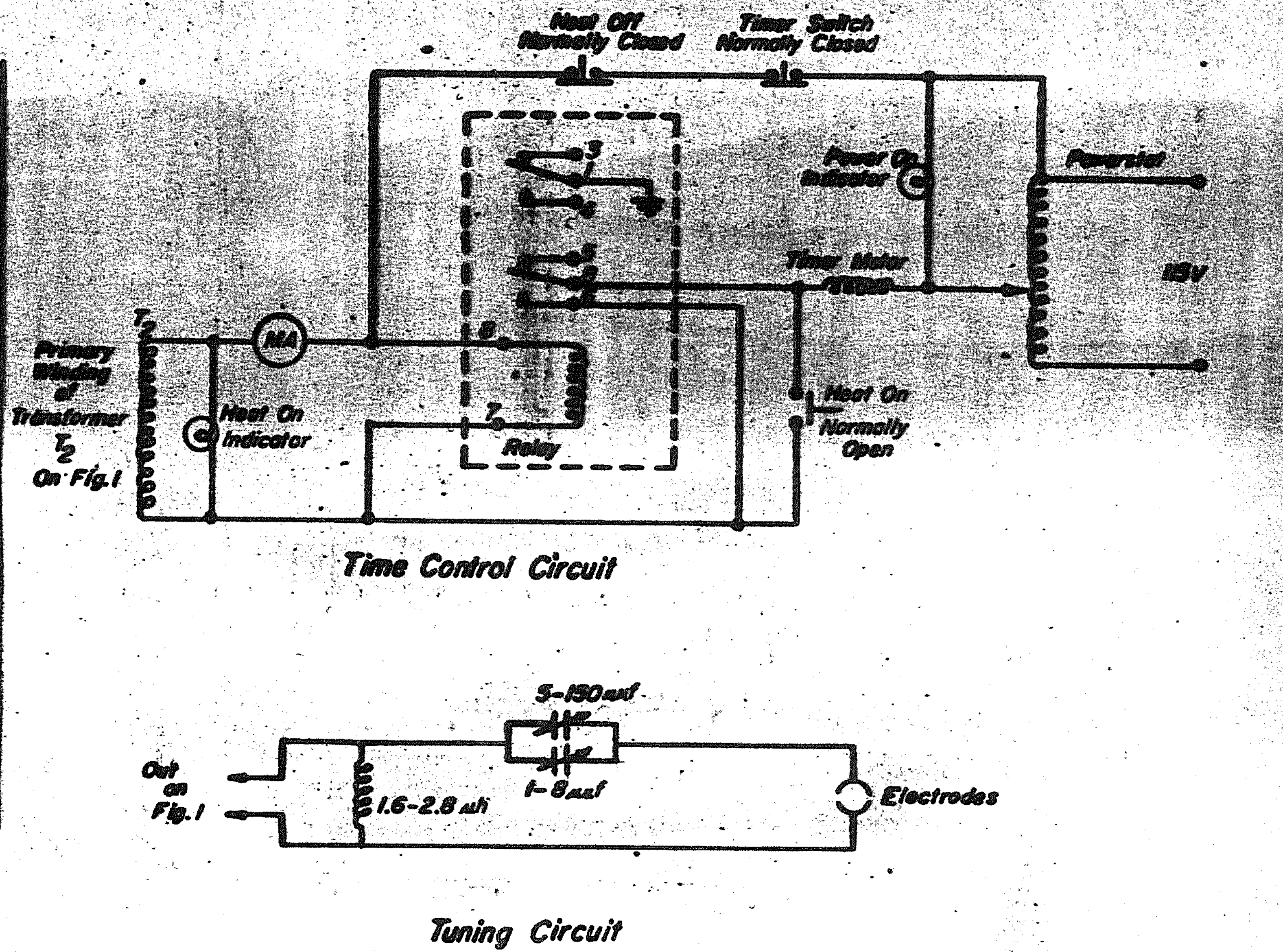


Figure 2. Schematic of timer and external tuning circuits.

TITLE: EFFECT OF ADDITION OF HEXADECANOL TO SOIL UPON TRANSPIRATION OF CORN PLANTS

LINE PROJECT: SWC-11-gG1 CODE: Ariz.-WCL-10

INTRODUCTION:

Efficiency of water use would be enhanced if transpirational losses could be reduced without depressing yields. Long-chain alcohols forming monomolecular layers have been found to lower evaporation from ponds, and certain reports indicate that addition of these substances to soil may bring about significant reductions in evapotranspiration. Carefully controlled experiments are needed to confirm such reports.

PROCEDURE:

Accordingly, a greenhouse experiment was performed at the U. S. Water Conservation Laboratory, Tempe, Arizona, to study the effect of long-chain alcohols on evapotranspiration from corn. The experiment was begun in February and completed in April 1961. The variables under investigation were: (1) kind of long-chain alcohol, (2) placement, and (3) dosage. Commercial preparations of hexadecanol and octadecanol were compared by placing different known amounts in a band 8 cm below the soil surface or by mixing the substances throughout the soil. Dosages of 0, 1, 5, and 25 g of powdered alcohol were used per pot, containing 3 kg of air-dry soil.

For statistical purposes the experiment was designed as a split-split plot, the main plots consisting of placement alternatives. The type of long-chain alcohol was designated by the sub-plots, whereas the dosage rate comprised the sub-sub plots. There were three replications oriented in an east-west line, so that environmental variation along the bench would be minimized within a given treatment. All treatments were randomized according to the standard split-plot design. In addition, one of the six rows of eight pots was shifted daily, from the south side of the bench to the next row north (while the northernmost row was changed to the south edge). This, in addition to placement of a 2" x 6" Styrofoam board 6 feet long at the southern edge of the bench next to the south row of pots, was to minimize the greater amount of sun's heat on the south in comparison to the north edge of the bench.

The plant studied was corn, Zea mays, variety WD456xKB397, Colorado State University, from the same seed lot used by Dr. S. R. Olsen in a parallel experiment at Fort Collins, Colorado. Six grains were planted per can; the resulting seedlings were thinned to three located at the center of the can and were grown for eight weeks. Air temperatures in the greenhouse ranged from 18 to 30 C. Soil temperatures were not allowed to exceed 30 C. This temperature control was achieved by use of a 52%-shade saran plastic screen over the greenhouse bench. However, the shading reduced the light intensity to a value of about 2500 foot-candles. The water vapor added by means of evaporative coolers tended to stabilize the moisture content of the air.

Number-10 tin cans were used with plastic liners. The soil was Adelanto silty clay loam from the surface two feet at the Laboratory grounds. It was brought approximately to the minus one-third bar pressure potential, 0.28 by volume, by addition of the calculated amount of distilled water to the air-dry soil, and restored to this value periodically by replacement of the water lost by evapotranspiration.

Daily replenishment of water immediately after the 6:00 A. M. weighing led to apparent aeration difficulties. Consequently, later in the growth period water was added when about one-half the available water was used, thus improving the growth. Nitrogen and phosphorus fertilizers were added when deficiency symptoms developed. The fertilizer additions effectively cured the deficiencies, but the combination of poor aeration and mineral deficiency eventually led to a loss of one or two plants in several pots.

When the plants were 35 cm. tall, the plastic liner in each can was closed firmly around the base of the plants, thus sealing off the soil from evaporation; the ensuing water loss thus occurred only from the plants, as transpiration. At this stage of growth the plants used about one-half the available water three days after watering. Therefore a three-day drying cycle was established. After three days of transpiration, the plastic bags were opened, leading to evapotranspirational loss during a succeeding 3-day cycle. After a total of two 3-day cycles of transpiration alternated with evapotranspiration, the experiment was ended. After harvest of the plants, fresh and dry weights were obtained of roots and shoots. During early growth, height measurements were made to study differential growth under different rates of application of long-chain alcohols.

RESULTS AND DISCUSSION:

The results are based on data for both hexadecanol and octadecanol obtained in the first 18 days. Data obtained just before harvest are tabulated for the octadecanol treatment only, because there were several pots with missing plants in the hexadecanol treatment. These data for octadecanol include two 3-day cycles of transpiration and evapotranspiration obtained in the eighth week, the results obtained during the poor growth midway through the experimental period being eliminated from consideration. None of the comparisons of treated with its corresponding control value in Table 1 showed a statistically significant difference, according to an analysis of variance.

Visual symptoms of early stunting of plants treated at the 25-g rate in both the hexadecanol and octadecanol treatments were evident, especially in the mixed treatment. The apparent toxicity was confirmed by leaf measurements and dry-weight data obtained when the seedlings were thinned from six to three per pot. At the end of the experiment, careful observation of the soil for visual evidence of persistence of the long-chain alcohols in the soil showed no obvious particles of the chemicals in the mixed treatment. On the other hand, the banded treatment showed very evident remnants of the original "pancake" of applied chemical, even at the 1 g dosage rate. The lack of visual evidence of the chemicals in the mixed treatments does not necessarily mean that the long-chain alcohols decomposed, since they were very finely distributed and not easily visible in the original preparation of the soil. Also, a surface tension measurement of water containing the soil from the 25-g mixed treatment of octadecanol indicated the presence of a surfactant. It is likely, nevertheless, that less chemical remained in the soil at the end of the experiment in the mixed treatment than in the banded application. Despite the early stunting, the final dry weight values were identical for treated and untreated plants, 6.73 g per pot.

Transpiration values are shown in Table 2, and evapotranspiration in Table 3. Again, no statistically significant differences due to placement, kind of chemical, or dosage rate were observed. These data indicate that under the conditions of this experiment, hexadecanol and octadecanol did not cause decreased transpiration or evapotranspiration in soil-grown corn plants.

SUMMARY AND CONCLUSIONS:

Corn was grown in the greenhouse in a three-replicate experiment for eight weeks, during which time evapotranspiration was determined by the weight-loss method. The effect on evapotranspiration of additions of hexadecanol or octadecanol to soil was studied, the two powdered alcohols being used at four dosages (0, 1, 5, and 25 g per pot, containing 3 kg of air-dry soil) and with two placement alternatives (thoroughly mixed or banded 8 cm below the surface). During the first 18 days from seeding there was no significant effect upon evapotranspiration by the above chemicals. During the eighth week of growth, two cycles of evapotranspiration showed no effect of octadecanol on lowering water loss as compared to control values. Hexadecanol results were not used, due to missing plants. An early tendency to stunting at the 25-g dosage rate did not result in any significant difference in final dry weight between treated and control plants.

PERSONNEL: W. Ehrler and C. H. M. van Bavel (Advisory)

Table 1

CUMULATIVE EVAPOTRANSPIRATION FROM CORN

IN AN 18-DAY PERIOD AFTER PLANTING

TREATMENT	ET, g pot^{-1}
<u>Placement</u>	
Mixed	785
Banded	742
<u>Kind of Chemical</u>	
Hexadecanol	761
Octadecanol	766
<u>Dosage</u>	
A. Control vs. treated	
Control	788
Treated	755
B. Among treated	
1 g per pot	773
5 g per pot	766
25 g per pot	725

Table 2

WATER LOSS AS AFFECTED BY TREATMENT WITH OCTADECANOL

Transpiration (during two 3-day cycles)

Treatment	T, g pot^{-1}
Placement	
Mixed	368
Banded	340
Dosage	
A. Control vs. treated	
Control	358
Treated	352
B. Among treated	
1 g per pot	329
5 g per pot	361
25 g per pot	368

Table 3

WATER LOSS AS AFFECTED BY TREATMENT WITH OCTADECANOL

Evapotranspiration (during two 3-day cycles)

Treatment	ET, g pot^{-1}
Placement	
Mixed	495
Banded	486
Dosage	
A. Control vs. treated	
Control	483
Treated	493
B. Among treated	
1 g per pot	482
5 g per pot	494
25 g per pot	503

TITLE: WATER UPTAKE OF ALFALFA VARIETIES AS AFFECTED BY SOIL TEMPERATURE AND OTHER ENVIRONMENTAL FACTORS

LINE PROJECT: SWC-11-gG1 CODE: Ariz.-WCL-11

INTRODUCTION:

This project was begun in April 1961, and was concluded in January 1962. The objectives are (1) to study the rate of water absorption by roots of intact alfalfa plants as determined by the interaction between root temperature and the evaporative demand of the atmosphere, and (2) to study varietal differences in response to a given root temperature for use as a guide to interpretation of field behavior of alfalfa.

More quantitative information is needed to understand why in northern Nevada irrigated alfalfa plants wilt in early spring when the soil in the lower root zone still is at or above field capacity. Although poor aeration may be a contributing factor, a more likely cause is low soil temperatures accompanied by air temperatures high enough to induce rapid transpiration. Since factors of both the aerial and root environment are involved in wilting, the problem is complex; it is further complicated by the simultaneous variation of environmental factors in nature. Investigations in a plant-growth chamber would enable the factors of the aerial environment to be held constant, while root temperature could be controlled at several successively lower values. Conversely, at a given root temperature, various rates of transpiration could be induced by regulating the aerial environment.

PROCEDURE:

The experiments were carried out at the U. S. Water Conservation

Laboratory, Tempe, Arizona. The Controlled-Environment Room described in the Annual Report for 1960, pp. 135-138, has functioned well since the modifications described in the report were made. In addition, the two insulated tanks which were installed made possible control of root temperature from 5 to 35 C with a precision of 0.5 degree C. Alfalfa was grown in four separate experiments to determine low root temperature effects on transpiration under controlled environmental conditions.

Twenty-four 1-gallon cans in each temperature tank permitted six replications of four varieties of alfalfa to be grown under the same conditions of root and aerial environment for about seven weeks.

The cans were suspended from the lid to a sufficient depth that the level of the water bath was at the same height as the level of culture solution. Temperature measurements by thermocouples at different depths in several cans indicated a differential of 0.5 degree C or less from top to bottom of each can. A volume of 3.7 l of Hoagland nutrient solution, with a concentration of 10 meq/l, was used per can, with constant aeration. Control of pH and maintenance of the original electrolyte concentration by means of replenishment or complete replacement of the nutrient solution brought about vigorous growth of the four alfalfa plants in each can. At harvest, the total leaf area per pot ranged from 20 to 30 dm^2. Leaf area was determined by relating the fresh weight of a known area (from discs punched from many leaflets) to the total fresh weight of leaf blades stripped from all plants per pot.

When the transpirational loss ranged from 200 to 300 g pot^{-1} day^{-1} under "standard conditions" (air temperature 25 C, relative humidity 56%, root temperature 24 C) an experimental variable was established. For periods ranging from one to three days, a low root temperature was maintained in one tank. Transpiration rates per pot in both the reference and the low-temperature tanks were carefully measured. This was done by actually determining water absorption by means of a point-gage. The lowered water level was restored to a fixed reference point by addition of water from a graduate cylinder. The leaf area was determined, and then the results were expressed as transpiration per square meter of leaf area per unit time. One variety of each of the four great groups of alfalfa in the United States was selected for this study, so that the results would be of broad scope.

RESULTS AND DISCUSSION:

I. Experiment 1.

Four alfalfa varieties, Buffalo, Ladak, Lahontan, and Moapa were germinated and grown in nutrient solution in the Plant Growth Room for eight weeks under the following conditions: fluorescent supplemented with incandescent light at 2000 ft.-c. intensity (0.2 ly min^{-1}) measured at the surface of the culture tank, 12-hour photoperiod, 25 C air temperature, 56% relative humidity, and 24 C root temperature. For at least a week before the experiment the daily transpiration was recorded. From inspection of these data, the pot having the lowest rate of loss was discarded, leaving five replications for each variety.

The objective of the experiment was to determine if lowering the root temperature from 24 to 10 C would decrease water absorption sufficiently to bring about wilting. The temperature lowering took four hours, transpiration being measured from the beginning of the cooling process. Under the ambient conditions described above, in which the saturation deficit was 14.0 mb, transpiration (as determined by measuring water absorption by non-wilted plants) was depressed somewhat by the lowered root temperature (see Figure 1). For the next 24 hours, the saturation deficit was maintained at 18.2 mb by having the air temperature 30 C, with a relative humidity of 57%. On the third day, the saturation deficit was raised to 28.4 mb. As shown in Figure 1, transpiration responded in an almost linear manner to the increased saturation deficit. However, the rate at 10 C root temperature remained about 20% below that of the control root temperature (24 C). At the last two points in the curve this difference was statistically significant (1% level). Water absorption apparently was being hindered by the low root temperature, but at no time was absorption sufficiently less than transpiration to bring about wilting. The Lahontan variety transpired significantly less per square meter of leaf area than Moapa.

II. Experiment 2.

Since 10 C did not depress water absorption enough to induce wilting even at very high transpiration rates, a second experiment was carried out in which the root temperature was lowered to 5 C. Only Moapa was used, at seven weeks from germination. Ambient conditions were the same during the growth period as for the first experiment, except for a somewhat lower light intensity (1680 ft.-c.) and the establishment of a low evaporative demand during the two days in which low root temperature was in effect, to prevent possible excessive dehydration of leaf tissues in the treated group. The experiment was designed as a paired comparison, with seven replications. One-half of the plants was transferred abruptly from 26 to 5 C root temperature, while the other half remained at 26 C. Transpiration occurred at a saturation deficit of 6.0, and 4.8 mb, respectively, for two days. The treated plants wilted toward the end of the first day, but recovered overnight. The 70 per cent reduction in transpiration due to the first 24-hour period of exposure to 5 C contrasts sharply with the 20 per cent reduction obtained earlier at 10 C. During the following day, however, transpiration at the low root temperature was reduced only 58 per cent.

III. Experiment 3.

Six replications of the same four varieties used in the first experiment were grown to an age of 7 weeks under "standard" ambient conditions, except for a decreased light intensity, 1400 ft.-C. To mitigate the growth reduction of plants exposed to low root temperature, the length of experimental period was reduced to one day. In two hours the root temperature in one tank was lowered from 26 to 5 C, and remained constant for an additional 22 hours; the control tank stayed at 26 C. Fairly severe wilting occurred in the cold-treated plants in late afternoon, followed by overnight recovery. Transpiration rate per square meter of leaf area was reduced 68 per cent, a value in excellent agreement with the Moapa results from Experiment 2. It is noteworthy that even the shortened exposure effected a 16 per cent decrease in fresh weight of the blades (a 12 per cent decrease in dry weight). There were no significant differences among varieties in transpiration rate per square meter of leaf area.

IV. Experiment 4.

The four varieties Buffalo, Ladak, Lahontan, and Moapa were grown for seven weeks at 25 C and 56 per cent relative humidity, and then maintained for two days at 30 C (a saturation deficit of 10 mb). The photoperiod was the same as before, 12 hours, and the intensity was 1400 ft.-c. during the experiment. Each variety was replicated five times. Before the lights came on automatically, the root temperature in one tank was lowered from the control setting of 28 to 9 C. The objective was to measure transpiration for successive two-hour intervals under a step-wise increase in saturation deficit (induced by a progressively lower relative humidity). However, the plants in the 9 C tank soon wilted, even at the low saturation deficit of 10 mb, which was the initial value, and the lowest deficit obtainable at 30 C air temperature. After recovery from the slight wilt, the transpiration rate for all plants was followed during two-hour intervals in which the saturation deficit was successively 6.7, 13.0, 17.5, and 20.0 mb. Since wilting still had not reoccurred at the end of the day, the last setting was maintained overnight. The next morning saturation deficits of 32.2, 44.6, and 44.9 mb were developed for three more 2-hour periods, the last two values being the highest that could be reached in the Growth Room at that time. During the last period the root temperature was adjusted downward from 9 to 5 C, and was allowed later to sink steadily to 5, 4, and finally to 3 C during the last half hour. The data plotted in Figure 2 in general agree with those of Figure 1, in that the transpiration curve increases linearly with greater saturation deficits over the lower range, but begins to fall off at rather high values of saturation deficit. This generalization applies to both the control and low-temperature treatments. The lower temperature (9C) again resulted in a consistently lower water absorption at the various saturation deficits. The mean for the first six two-hour periods was depressed from 415 at 28 C to 237 G m^{-2} 2 hr^{-1} at 9 C, a 43% reduction. However, no wilting occurred at the 9 C root temperature, even though there was very rapid transpiration during the sixth two-hour period (estimated at 3500 g m^{-2} 24 hr^{-1}). Not until the root temperature was lowered to 5 C or below did water absorption begin to be reduced drastically. Although no wilting occurred even under these latter conditions, it is likely that a similar but longer interval would have led ultimately to wilting--as in experiments 2 and 3, in which exposure to a root temperature of 5 C for 24 hours or more brought about wilting even under a more moderate rate of transpiration (about 1500 g m^{-2} hr^{-1}). Wilting, which occurs when absorption is less than loss of water, depends on the root temperature, transpiration rate, and duration of the imbalance between the two processes. As in experiment No. 1, Lahontan transpired less per unit leaf area than Moapa.

SUMMARY AND CONCLUSION:

The effect of low root temperature and atmospheric saturation deficit on the transpiration of four alfalfa varieties was investigated in four controlled environment experiments. Water absorption by non-wilted plants was the measure of transpiration. Figure 1 sums up the results obtained in the first experiment. The transpiration rate of both control (24 C root temperature) and treated (10 C root temperature) plants increased almost linearly with increasing saturation deficit, but was consistently about 20% lower at the low root temperature than at the control value.

These data, obtained from three 24-hr periods of successively higher saturation deficits, in general are confirmed by the data from the fourth experiment, shown in Figure 2. Transpiration rates were measured only for two-hour intervals, but over a much greater range of saturation deficits. The transpiration curve increases linearly over the lower range, but begins to fall off at rather high values of saturation deficit, both in the control and treated plants. Again the low root temperature (9 C) resulted in a lower transpiration rate than did the control root temperature (28 C). However, water absorption at the low root temperature was not depressed sufficiently to induce wilting, even when for a two-hour period the root temperature was reduced to 5 C, and the concurrent transpirational loss was estimated to have been equal to 3500 g m^{-2} 24 hr^{-1}.

Experiments Nos. 2 and 3 utilized root temperatures of 5 C in comparison to 26 C under low evaporative conditions. Here the plants wilted after the first four hours of the 24-hour exposure (a total exposure of 48 hours in experiment No. 2) in spite of a saturation deficit of only 4-6 mb. The 68-70% depression of the transpiration rate occurring when the root temperature was 5 C for four hours or more contrasts sharply with the 20% depression noted at 9 or 10 C.

There did not seem to be any consistent varietal differences in transpiration rate per unit leaf area. Although the value for Lahontan was less than that for Moapa in the first and last experiments, there were no significant differences among the four varieties in experiment No. 3.

These experiments emphasize the fact that wilting, which occurs when absorption is less than transpiration, depends on the root temperature, concurrent transpiration rate, and the duration of the imbalance between the two processes. Results of this kind, with proper interpretation, may help explain field behavior of alfalfa.

PERSONNEL: W. L. Ehrler and C. H. M. van Bavel (advisory)

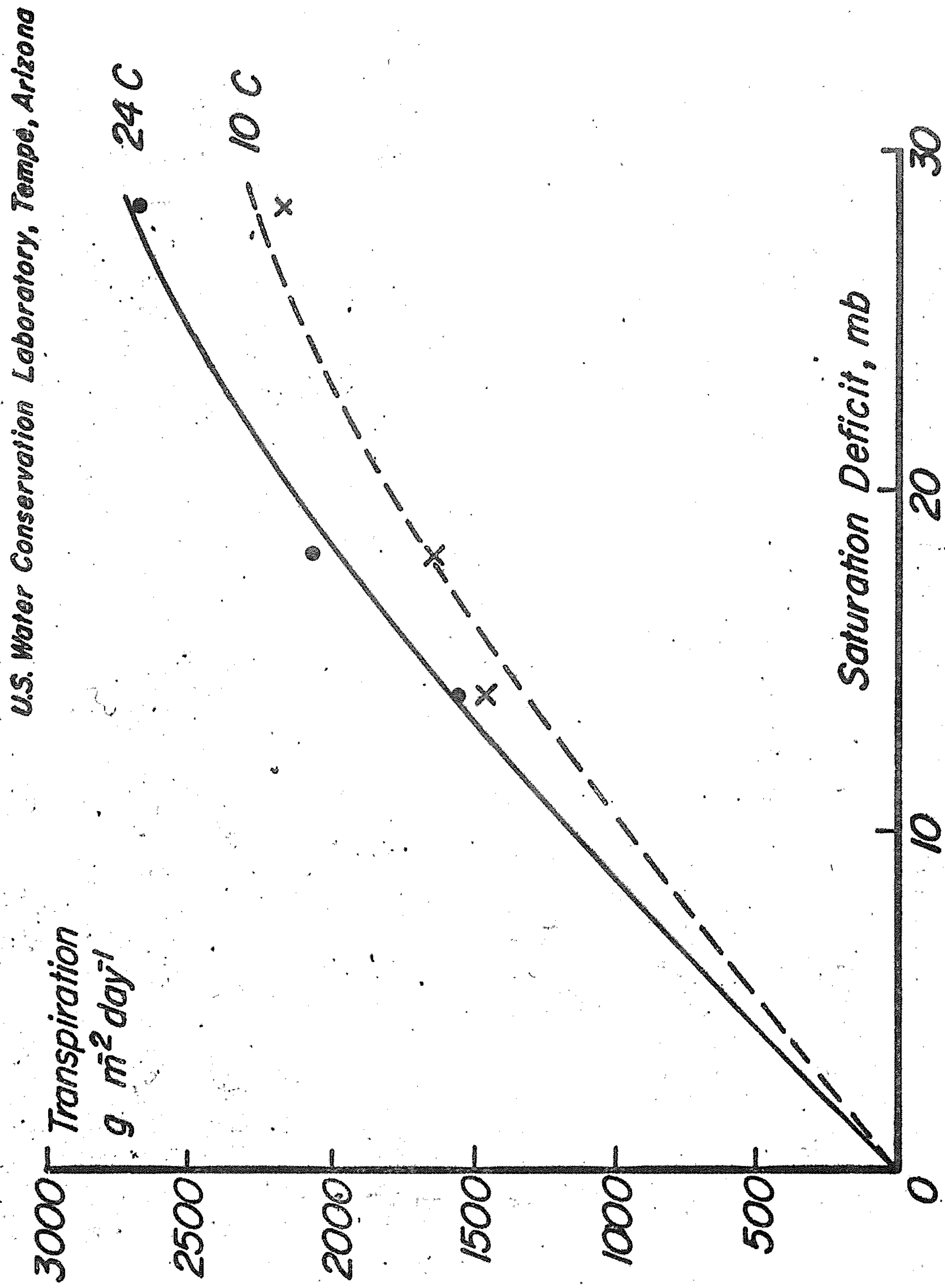


Figure 1. Alfalfa transpiration rate, mean of four varieties, as affected by root temperature and saturation deficit.

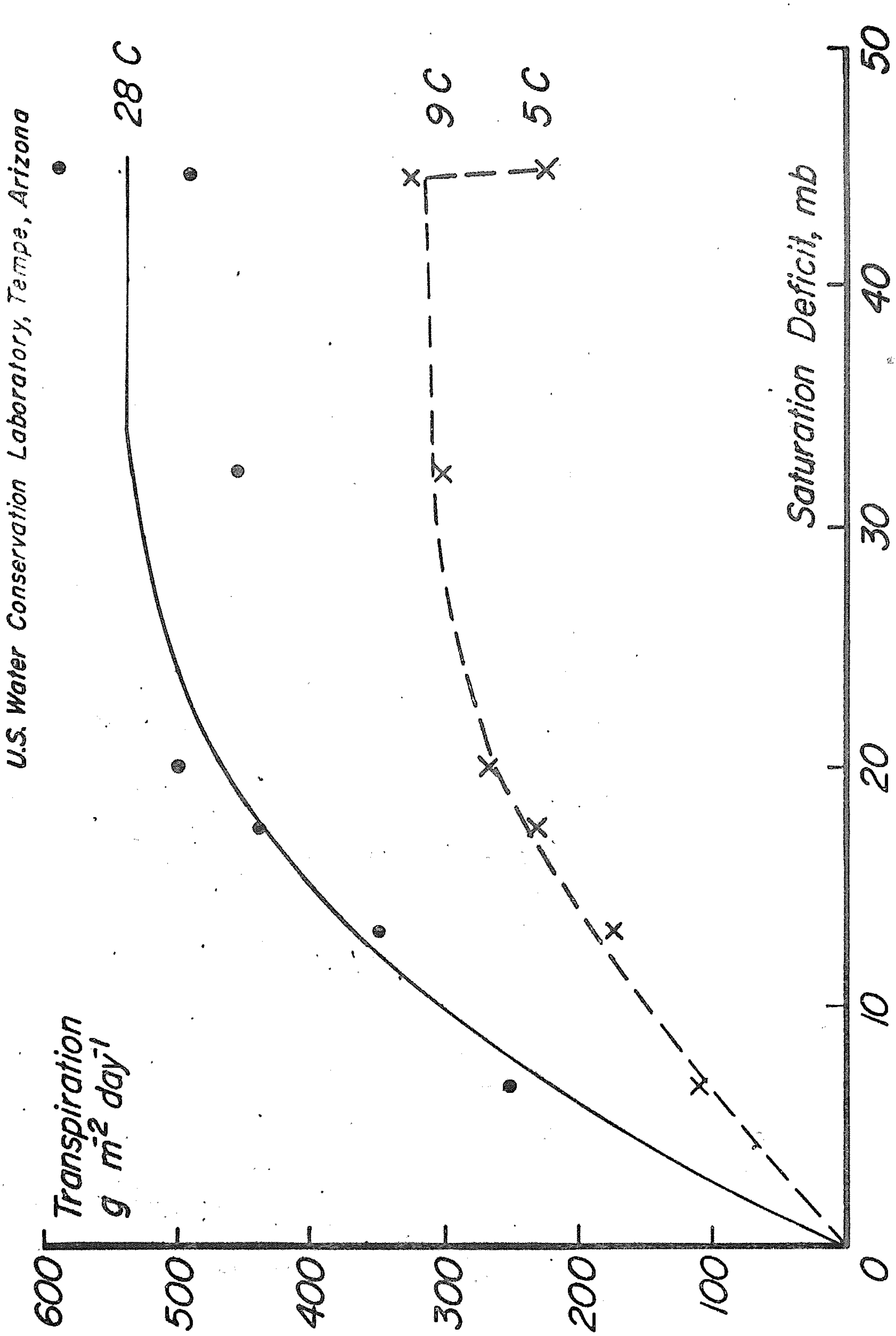


Figure 2. Alfalfa transpiration rate, mean of four varieties, as affected by root temperature and saturation deficit.

TITLE: CONSUMPTIVE USE OF WATER BY CROPS IN ARIZONA

LINE PROJECT: SWC-11-gG11 CODE: Ariz.-WCL-23

INTRODUCTION:

See previous Annual Report.

PROCEDURE:

Consumptive-use measurements were made at the following locations in 1960-61.

1. Cotton - Cotton Research Center
2. Blue Panicum - Mesa Experiment Farm
3. Cole Crops (Cabbage, Broccoli, Cauliflower) - Mesa Experiment Farm
4. Potatoes - Mesa Experiment Farm
5. Sweet Corn - Mesa Experiment Farm
6. Cantaloupes - Mesa Experiment Farm
7. Grapes - Rancho El Dorado
8. Other vegetables - (Onions, Carrots, Lettuce) - Mesa Experiment Farm

RESULTS AND DISCUSSION:

Most vegetable crops require frequent early irrigations to germinate seed, maintain stands and to aid in placement of tensiometers. Therefore, it can be expected that early season consumptive and profile use may reflect an amount of deep percolation that is not measurable with present measuring techniques.

15 DAY INTERVAL USE AND "K" VALUES FOR VARIOUS CROPS IN ARIZONA 1961

		Cotton		Blue Panicum		Potatoes		Sweet Corn	
		Cu	K	Cu	K	Cu	K	Cu	K
Jan	1-15								
	16-31								
Feb	1-14					.03	.04		
	15-28					.14	.07		
Mar	1-15					1.50	.62	.03	.03
	16-31					3.20	1.25	.32	.12
Apr	1-15			2.31	1.06	5.25	1.76	.75	.25
	16-30	.16	.05	3.30	1.09	6.30	2.07	1.35	.44
May	1-15	.45	.14	3.60	1.07	5.10	1.51	2.70	.80
	16-31	.96	.25	4.00	1.04	.91	.55	6.56	1.71
June	1-15	1.50	.39	3.90	.99			6.60	1.68
	16-30	2.40	.55	4.20	.94				
July	1-15	3.60	.86	4.65	1.08				
	16-31	4.96	1.05	5.60	1.21				
Aug	1-15	5.10	1.27	4.50	1.12				
	16-31	4.48	1.10	3.84	.94				
Sept	1-15	3.75	1.10	3.15	.92				
	16-30	3.30	1.03	2.84	.88				
Oct	1-15	2.55	.93	2.40	.86				
	16-31	1.28	.48	1.44	.53				
Nov	1-15	.12	.15	.08	.40				
	16-30								
Dec	1-15								
	16-31								

15 DAY INTERVAL USE AND "K" VALUE FOR VARIOUS CROPS IN ARIZONA 1961

		Early Cabbage		Late Cabbage		Broccoli		Cauliflower	
		Cu	K	Cu	K	Cu	K	Cu	K
Jan	1-15	.15	.43	1.50	.81	1.35	.73	1.35	.73
	16-31			1.76	.85	1.92	.92	1.44	.69
Feb	1-14			1.68	.87	.42	1.00	.24	.57
	15-28			1.96	1.02				
Mar	1-15								
	16-31								
Apr	1-15								
	16-30								
May	1-15								
	16-31								
June	1-15								
	16-30								
July	1-15								
	16-31								
Aug	1-15								
	16-31	.88	.44	.64	.32	.72	.36	.48	.24
Sept	1-15	2.25	.62	2.25	.62	2.40	.66	1.50	.41
	16-30	2.85	.84	3.15	.93	3.45	1.02	2.70	.80
Oct	1-15	3.00	1.08	3.00	1.08	3.30	1.18	3.75	1.34
	16-31	2.56	.94	2.88	1.05	2.72	1.00	4.00	1.46
Nov	1-15	1.80	.81	2.40	1.08	1.95	.87	3.30	1.48
	16-30	1.35	.67	2.10	1.02	1.50	.74	2.70	1.33
Dec	1-15	1.05	.64	1.80	1.10	1.20	.73	1.95	1.19
	16-31	.96	.49	1.76	.90	1.44	.74	1.60	.82

15 DAY INTERVAL USE AND "K" VALUES FOR VARIOUS CROPS IN ARIZONA 1961

		Green Onions		Dry Onions		Carrots		Lettuce	
		Cu	K	Cu	K	Cu	K	Cu	K
Jan	1-15	1.35	.73	.80	.43	1.50	.82	.90	.48
	16-31	1.76	.85	1.28	.62	1.60	.77	1.28	.62
Feb	1-14	1.82	.94	1.54	.79	1.82	.94	.39	.93
	15-28	2.38	1.24	2.10	1.09	2.80	1.46		
Mar	1-15	3.15	1.30	2.85	1.18	2.55	1.01		
	16-31	4.48	1.70	3.75	1.43	1.04	.80		
Apr	1-15	6.80	2.01	6.90	2.32				
	16-30			2.52	1.35				
May	1-15								
	16-31								
June	1-15								
	16-30								
July	1-15								
	16-31								
Aug	1-15								
	16-31								
Sept	1-15								
	16-30								
Oct	1-15								
	16-31					.60	.34	.30	.17
Nov	1-15					1.65	.74	1.20	.54
	16-30	.30	.15	.15	.07	2.55	1.26	1.20	.59
Dec	1-15	.75	.46	.45	.27	1.95	1.19	1.05	.64
	16-31	1.04	.53	.56	.29	1.60	.82	.96	.49

15 DAY INTERVAL USE AND "K" VALUES FOR VARIOUS CROPS IN ARIZONA 1961

		Cantaloupes		Grapes	
		Cu	K	Cu	K
Jan	1-15				
	16-31				
Feb	1-14				
	15-28				
Mar	1-15				
	16-31	.14	.06	1.26	.43
Apr	1-15	.60	.19	1.50	.50
	16-30	1.20	.41	2.10	.70
May	1-15	1.80	.53	3.00	.89
	16-31	2.88	.74	6.40	1.70
June	1-15	5.40	1.38	5.10	1.33
	16-30	7.05	1.57	3.60	.82
July	1-15	2.73	1.42	1.47	.77
	16-31				
Aug	1-15				
	16-31				
Sept	1-15				
	16-30				
Oct	1-15				
	16-31				
Nov	1-15				
	16-30				
Dec	1-15				
	16-31				

RESULTS AND DISCUSSION:

Cotton graphs and data will be found under WCL-21.

The blue panicum was chiseled in the early part of the season in an attempt to rejuvenate the plants' vigor.

All vegetables were sampled under conditions that were fairly wet. Irrometers were used to indicate time of irrigation.

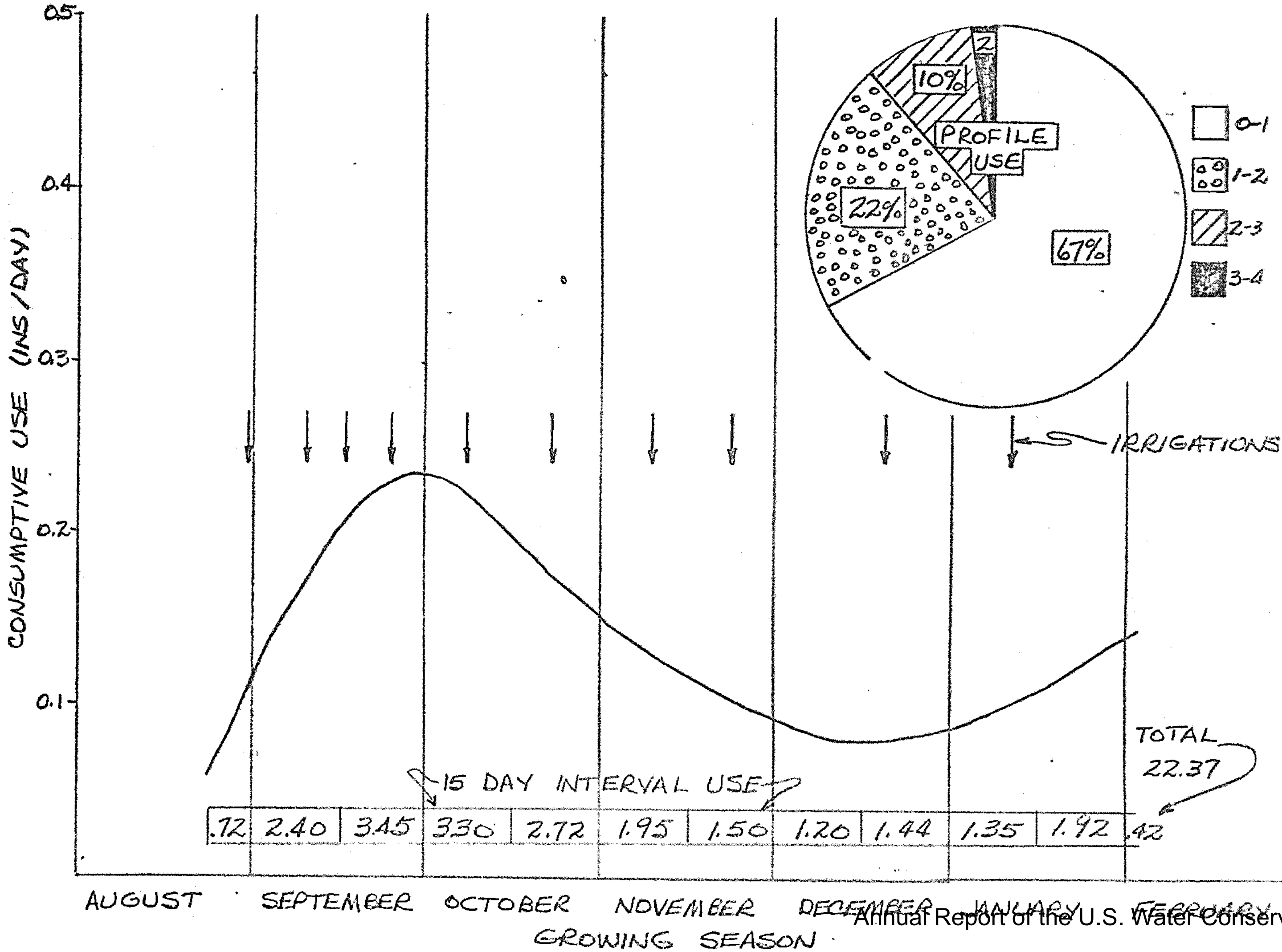
Although many samples were taken on the grapes, some bias may be indicated due to inadequate irrigations. The soil was underlain with sand, thus preventing any appreciable amount of lateral movement of water. Shortage of water during peak production period may have reduced yields.

PERSONNEL: Leonard J. Erie and Orrin F. French. Many of the consumptive use measurements were made in conjunction with experiments conducted on University of Arizona Experiment Farms.

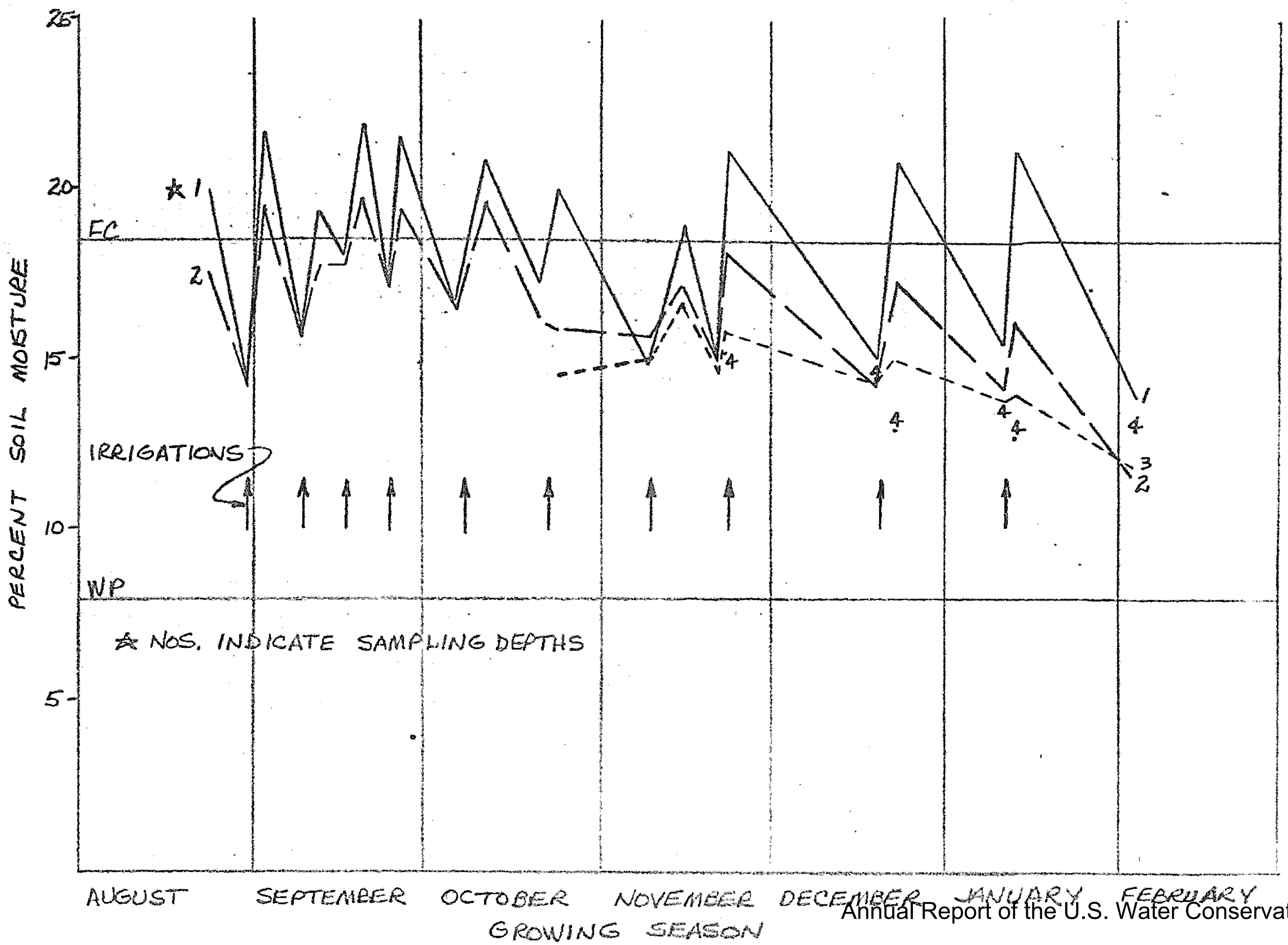
Vegetables - Dr. W. D. Pew, James Park

Grapes - George Sharples, Lowell True

CONSUMPTIVE USE - BROCCOLI
MESA EXP. FARM 1960-61



SOIL MOISTURE PERCENTAGE - BROCCOLI
MESA EXP. FARM - 1960-61



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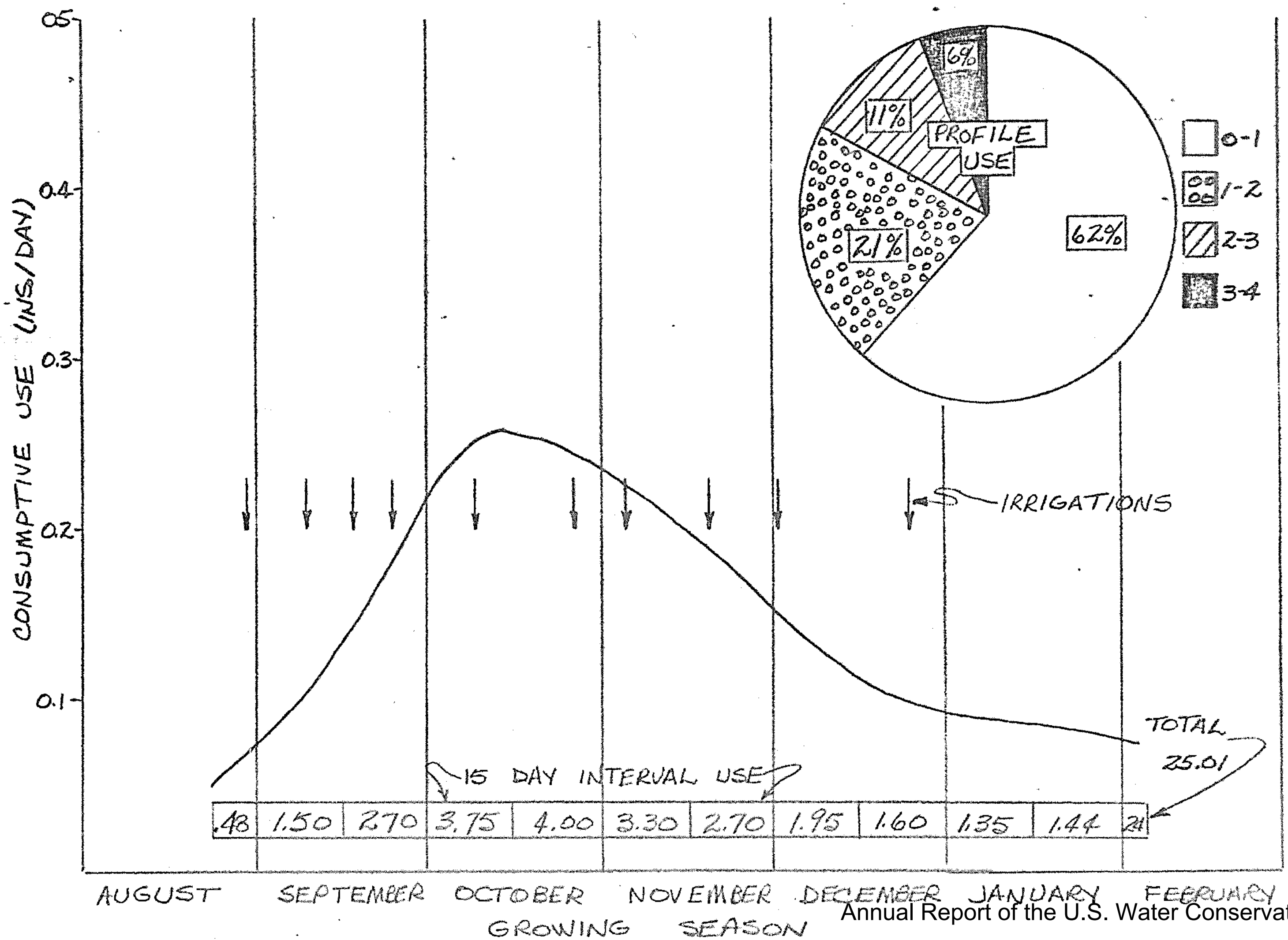
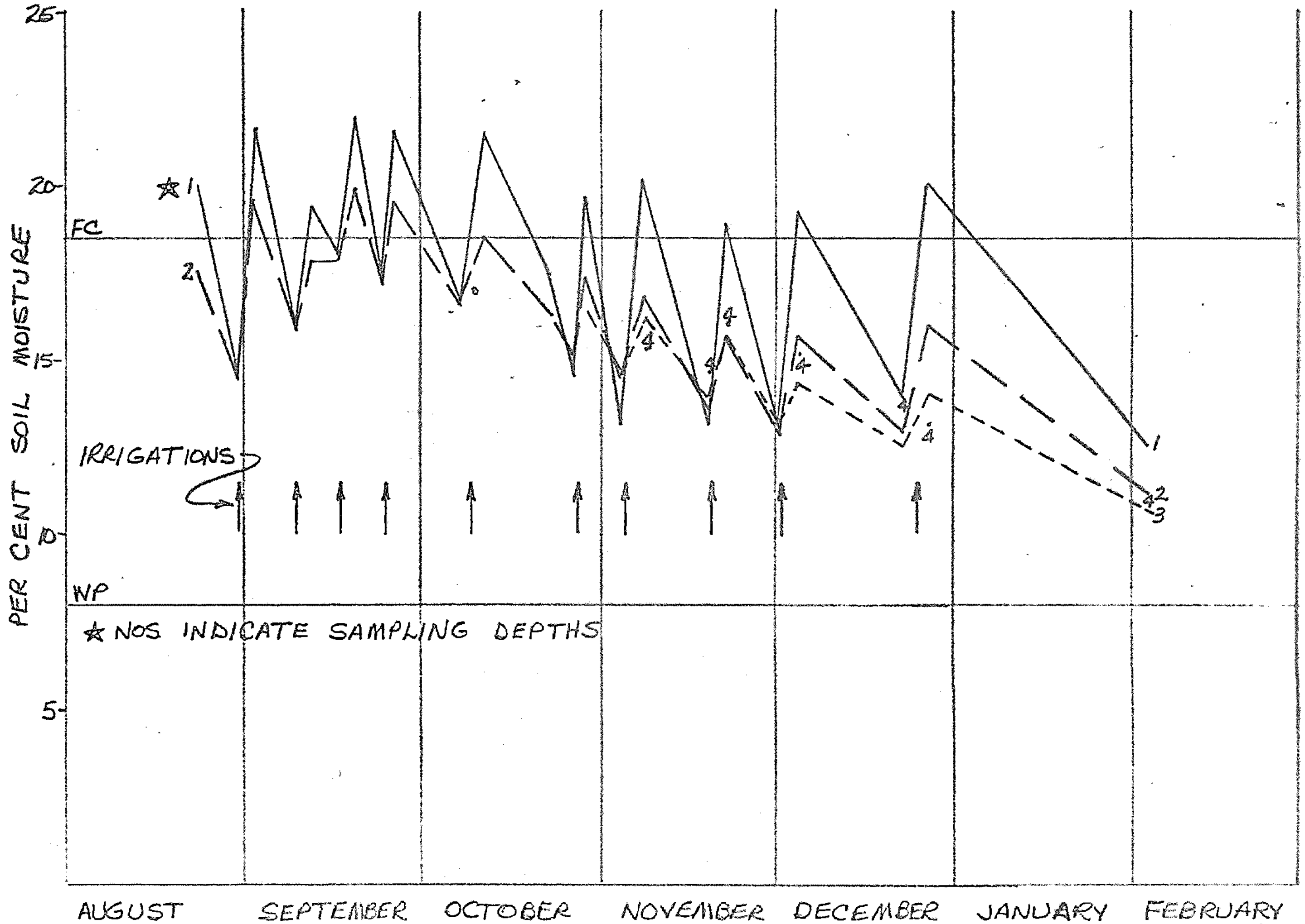
CONSUMPTIVE USE - CAULIFLOWER
MESA EXP. FARM 1960-61

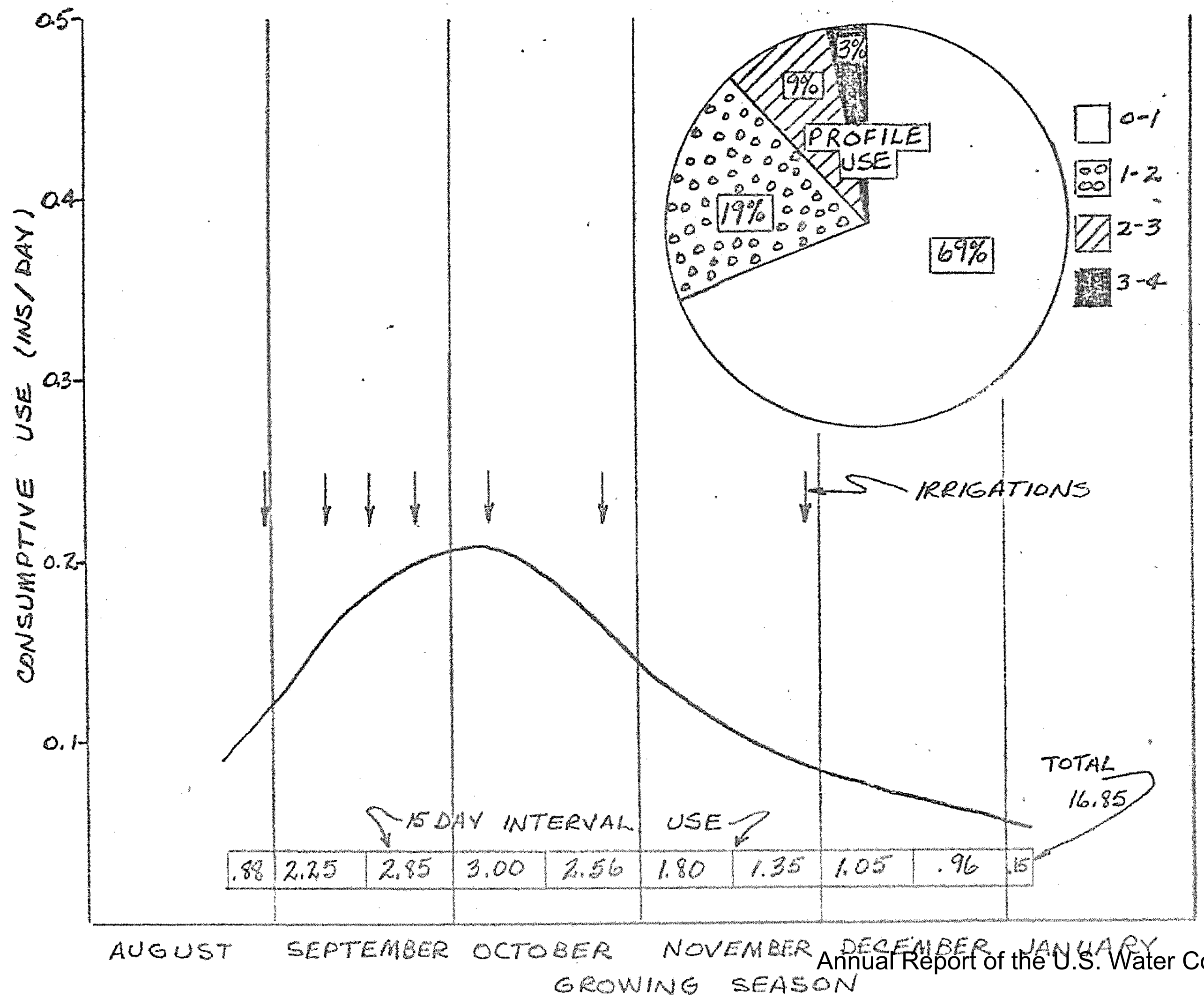


SOIL MOISTURE PERCENTAGE - CAULIFLOWER
MESA EXP. FARM 1960-61

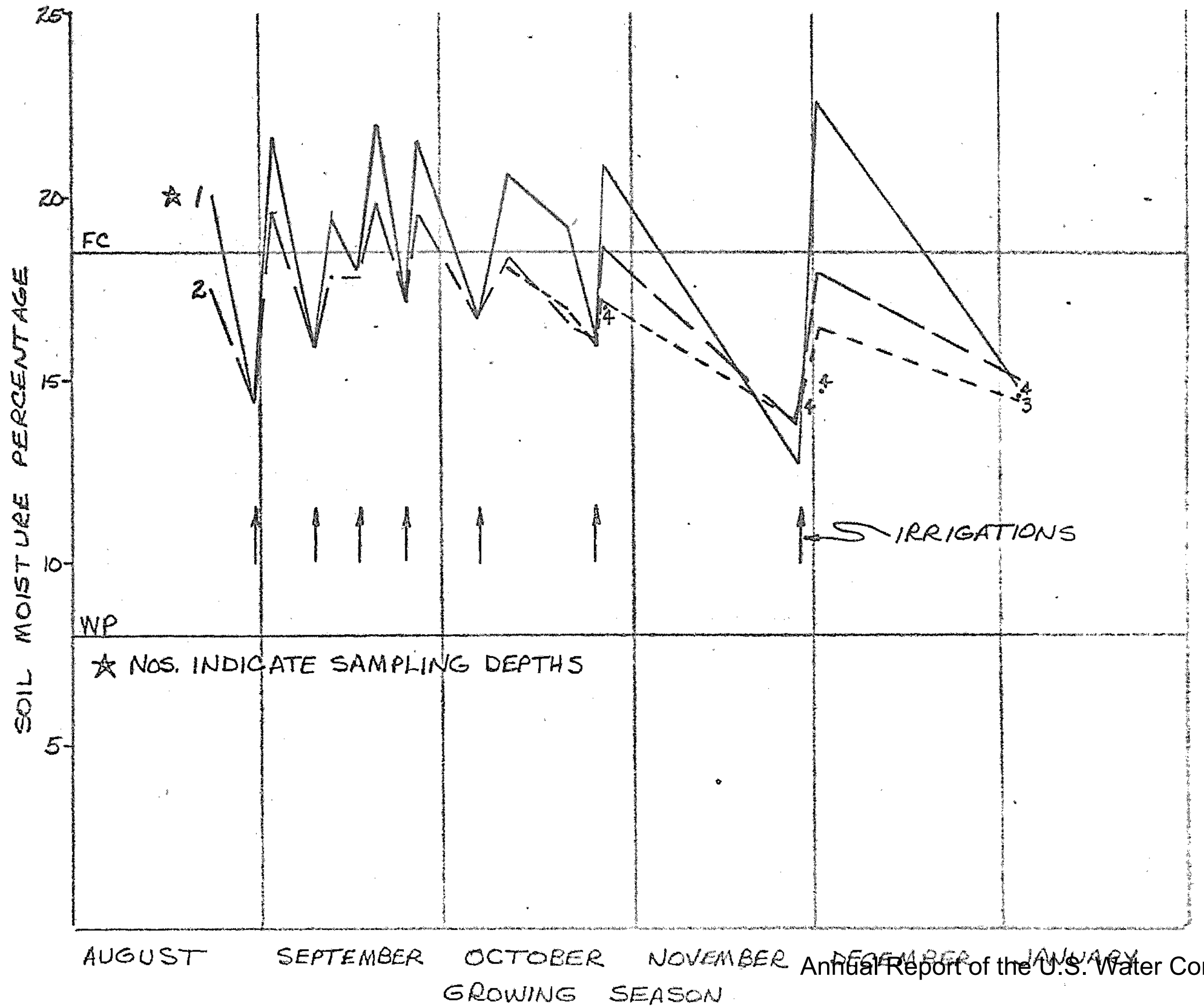


GROWING SEASON

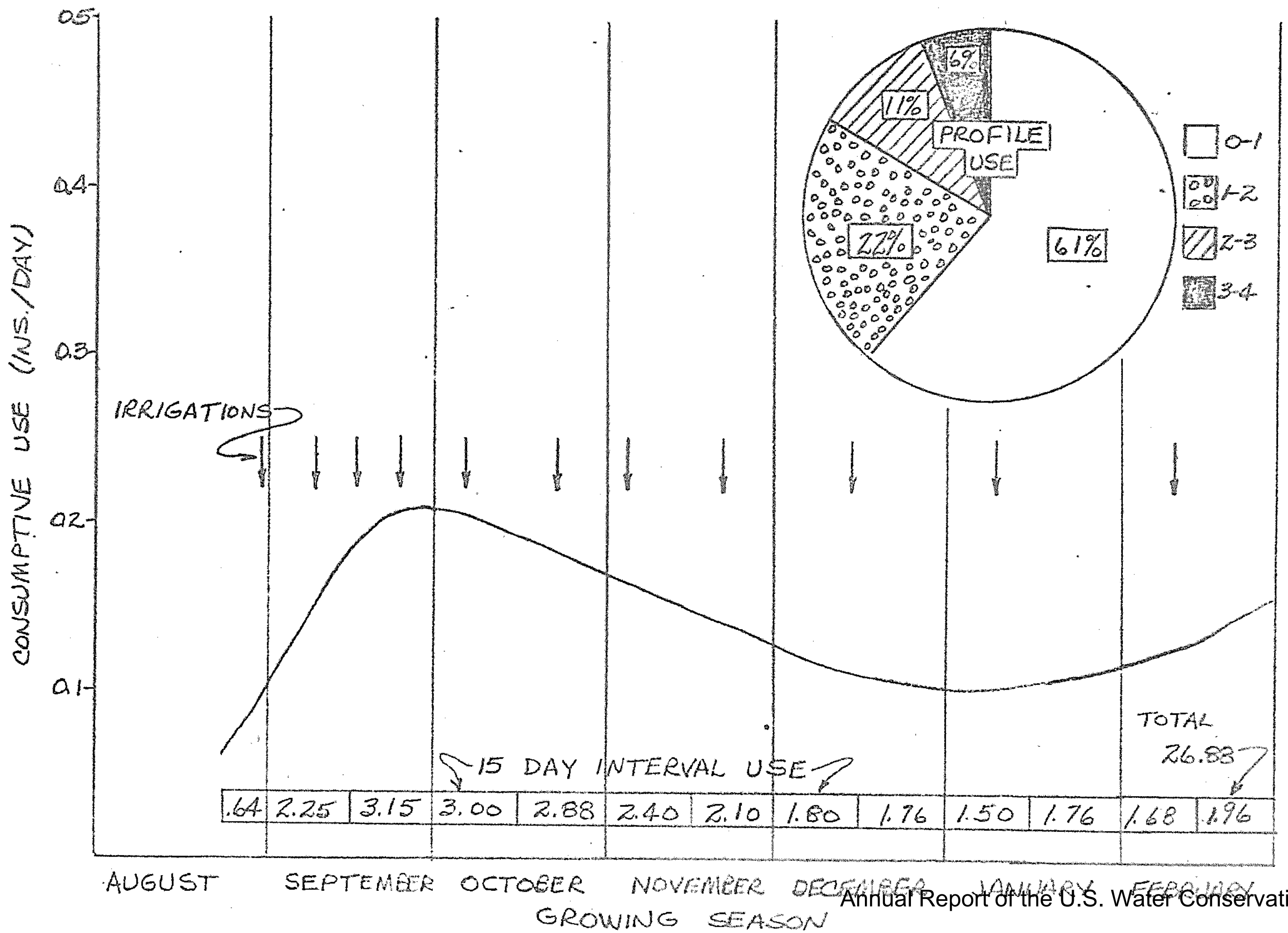
CONSUMPTIVE USE - EARLY CABBAGE
MESA EXP. FARM 1960-61

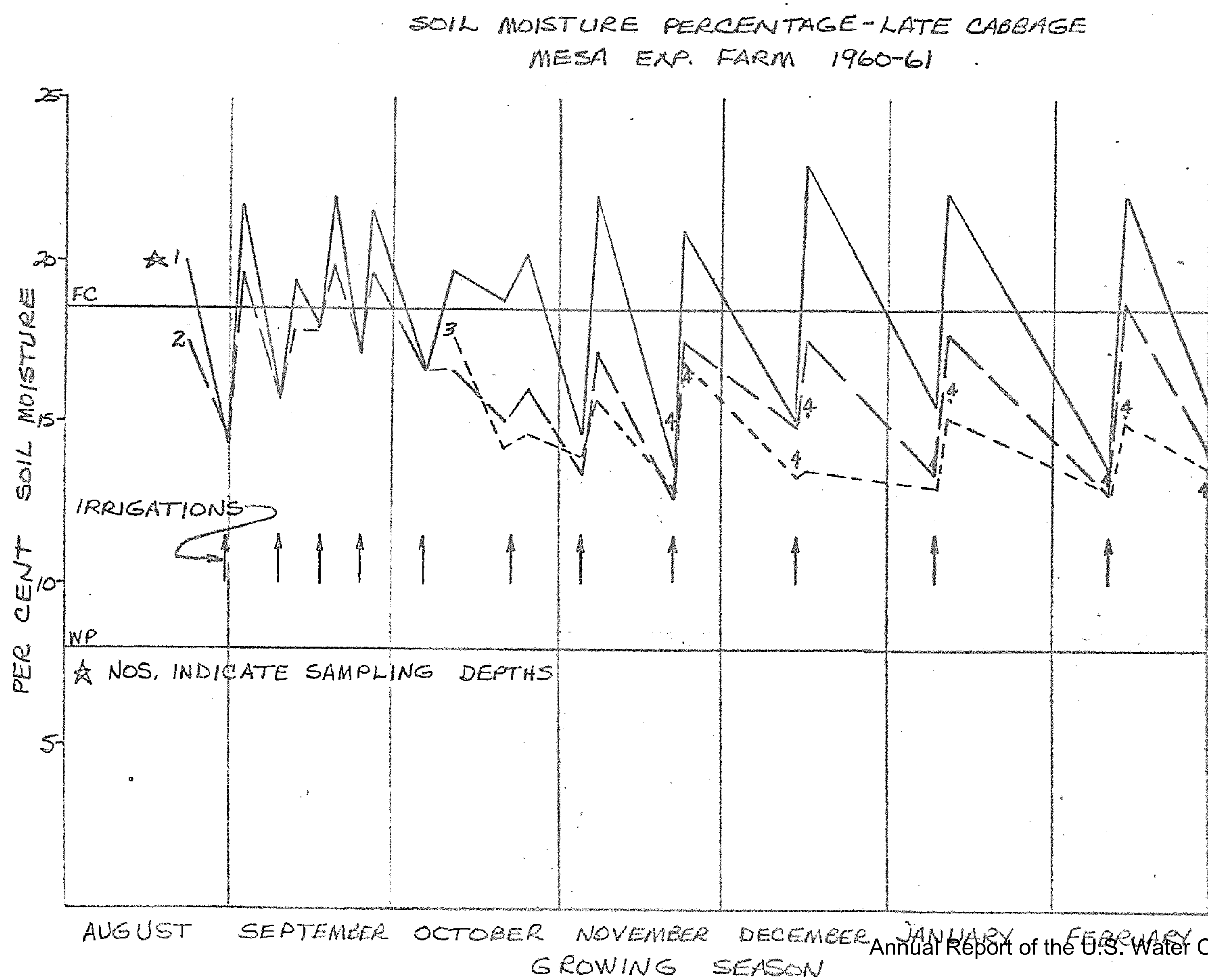


SOIL MOISTURE PERCENTAGE EARLY CABBAGE
MESA EXP. FARM 1960-61



CONSUMPTIVE USE - LATE CABBAGE
MESA EXP FARM 1960-61





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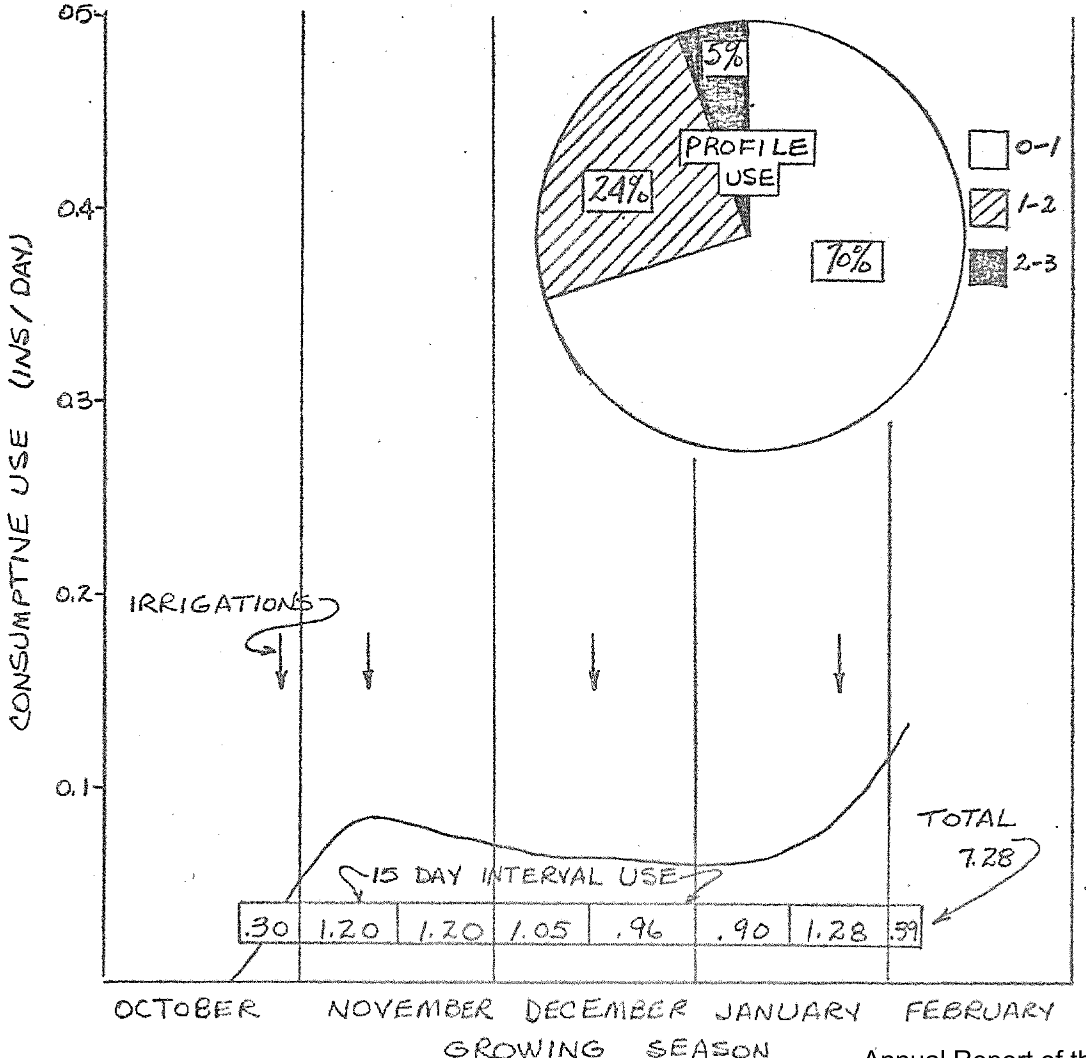
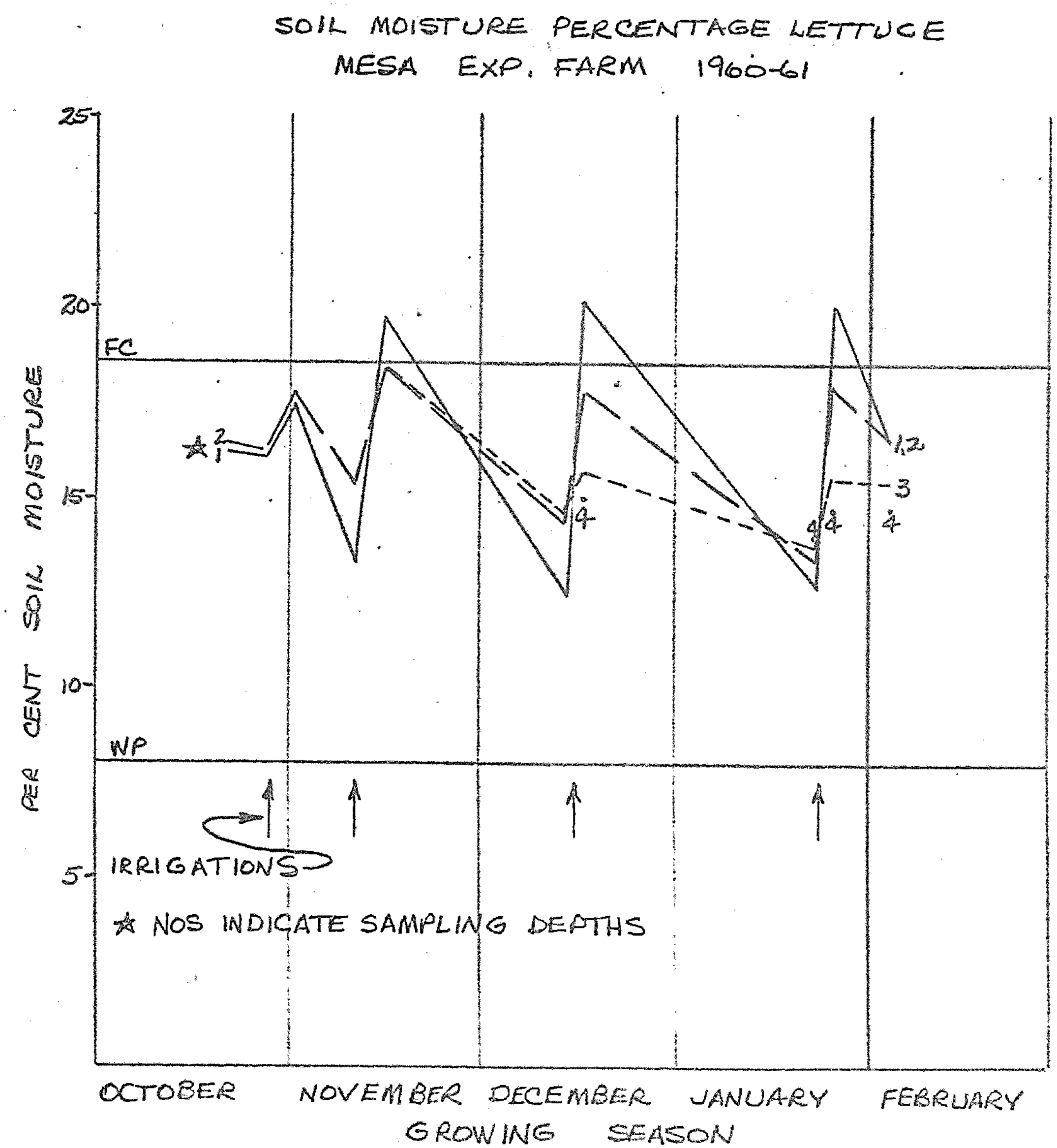
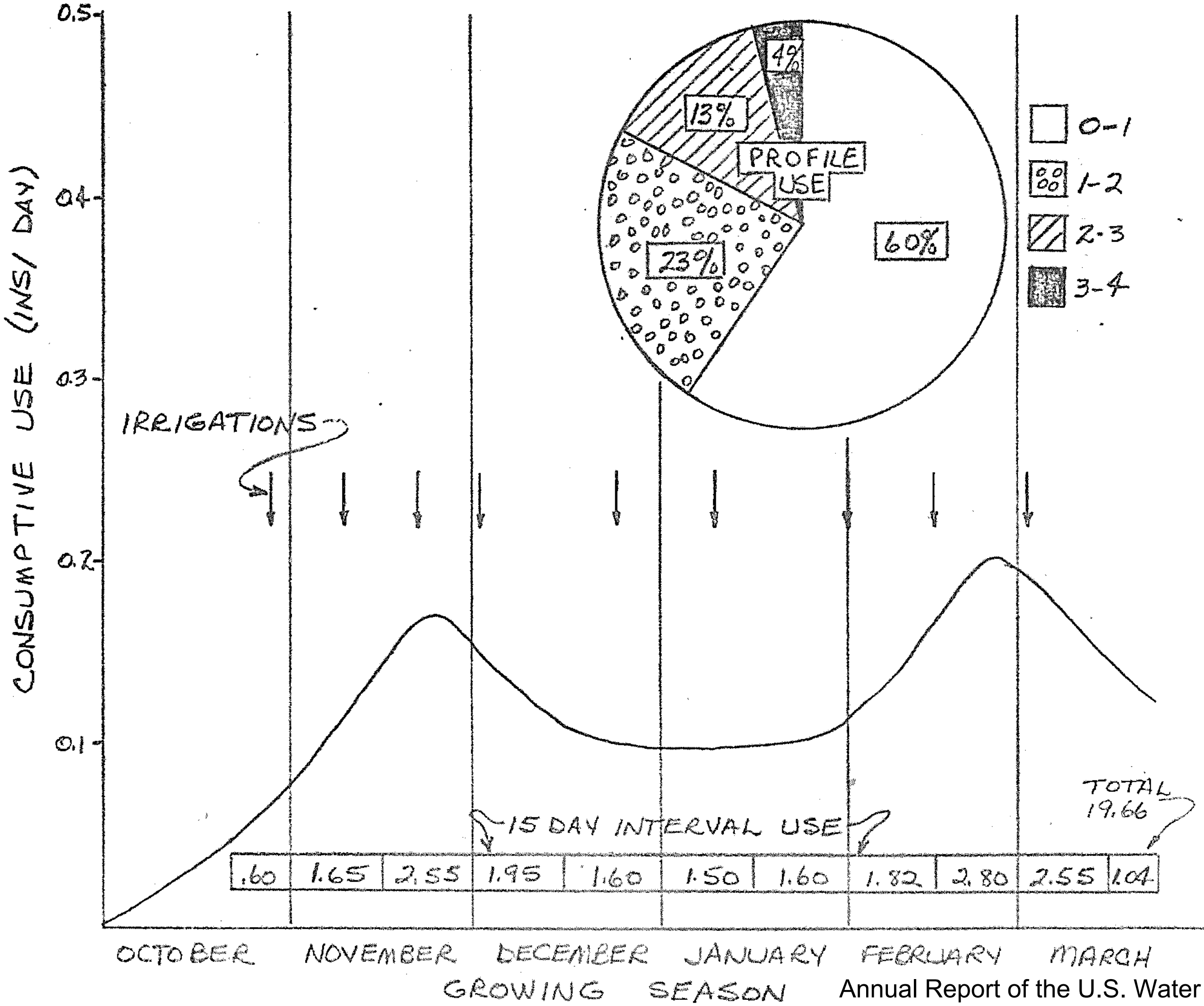
CONSUMPTIVE USE - LETTUCE
MESA EXP. FARM -1960-61



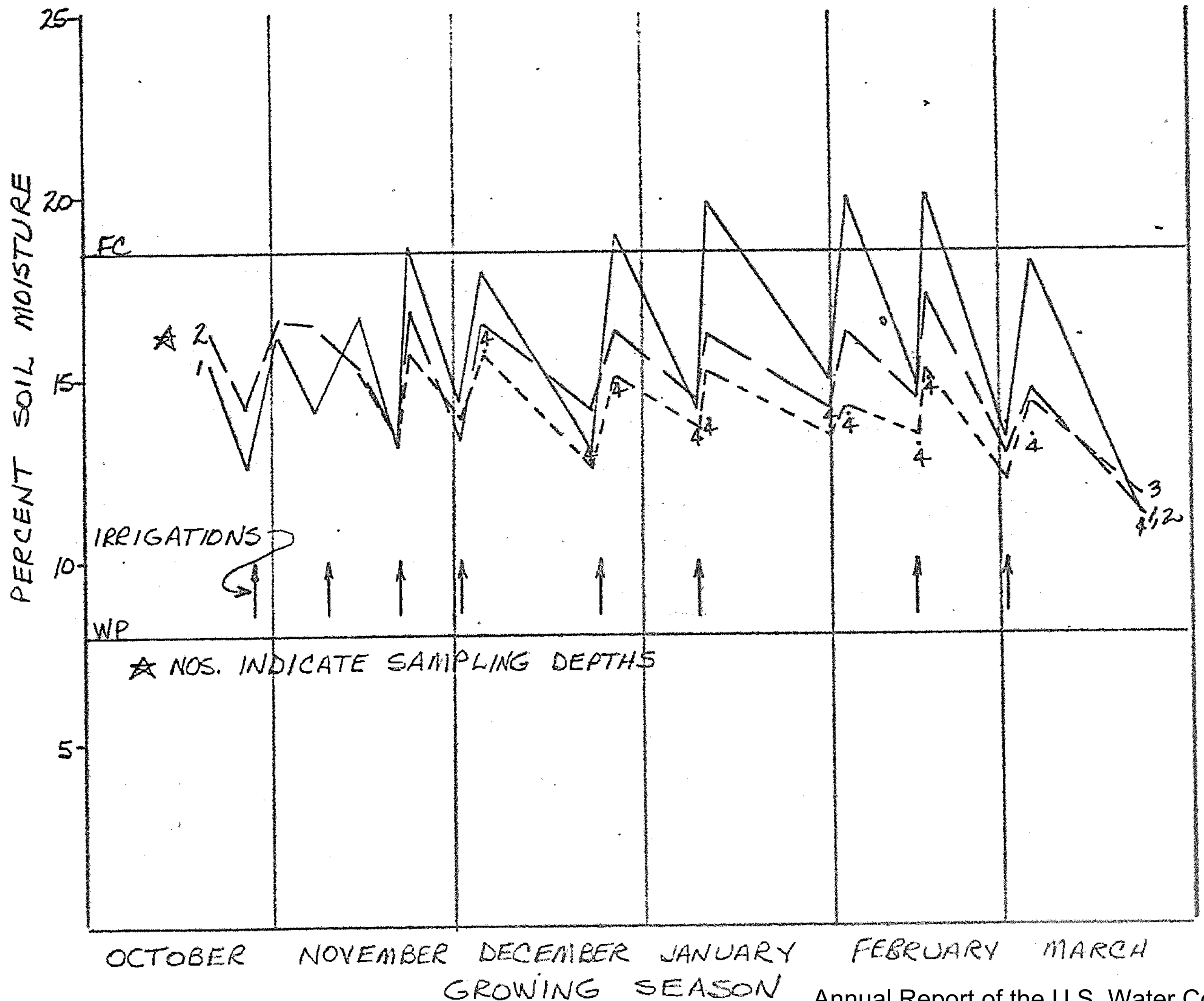

SOIL MOISTURE PERCENTAGE LETTUCE
MESA EXP. FARM 1960-61
25
20
15
10
5
FC
WP
PER CENT SOIL MOISTURE
2
1
1,2
3
4
IRRIGATIONS
☆ NOS INDICATE SAMPLING DEPTHS
OCTOBER
NOVEMBER
DECEMBER
JANUARY
FEBRUARY
GROWING SEASON

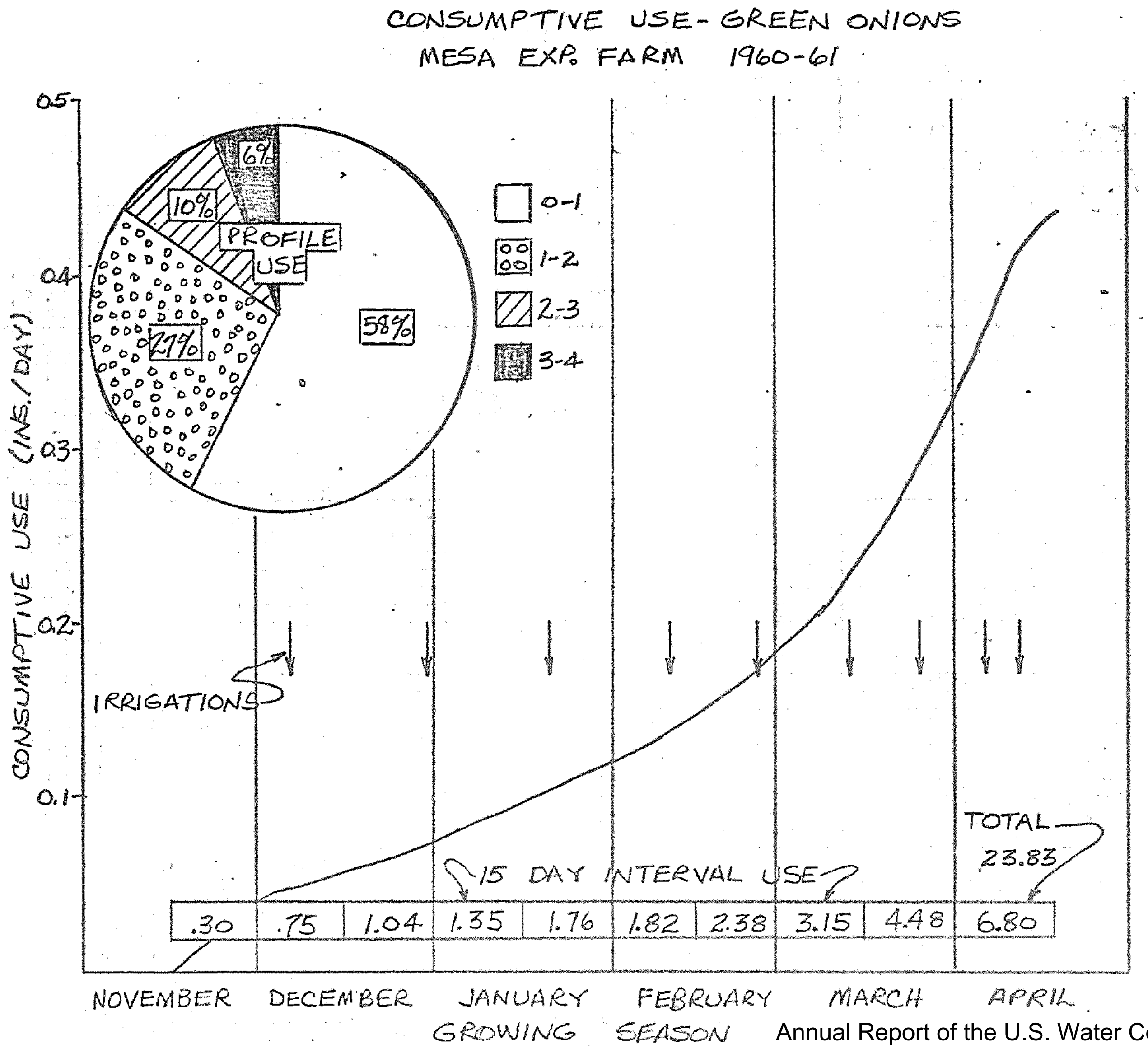
350

CONSUMPTIVE USE - CARROTS
MESA EXP. FARM - 1960-61

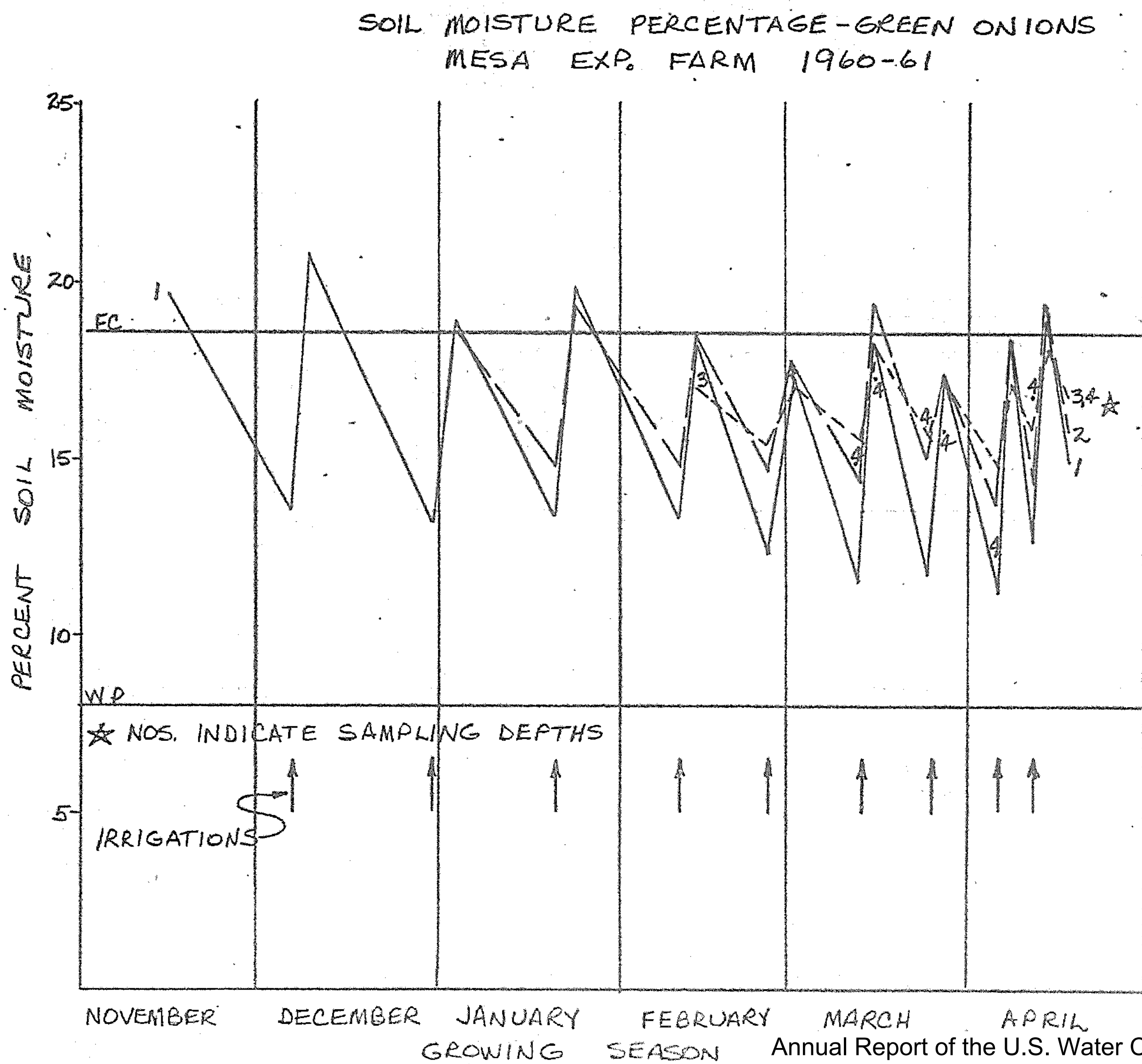


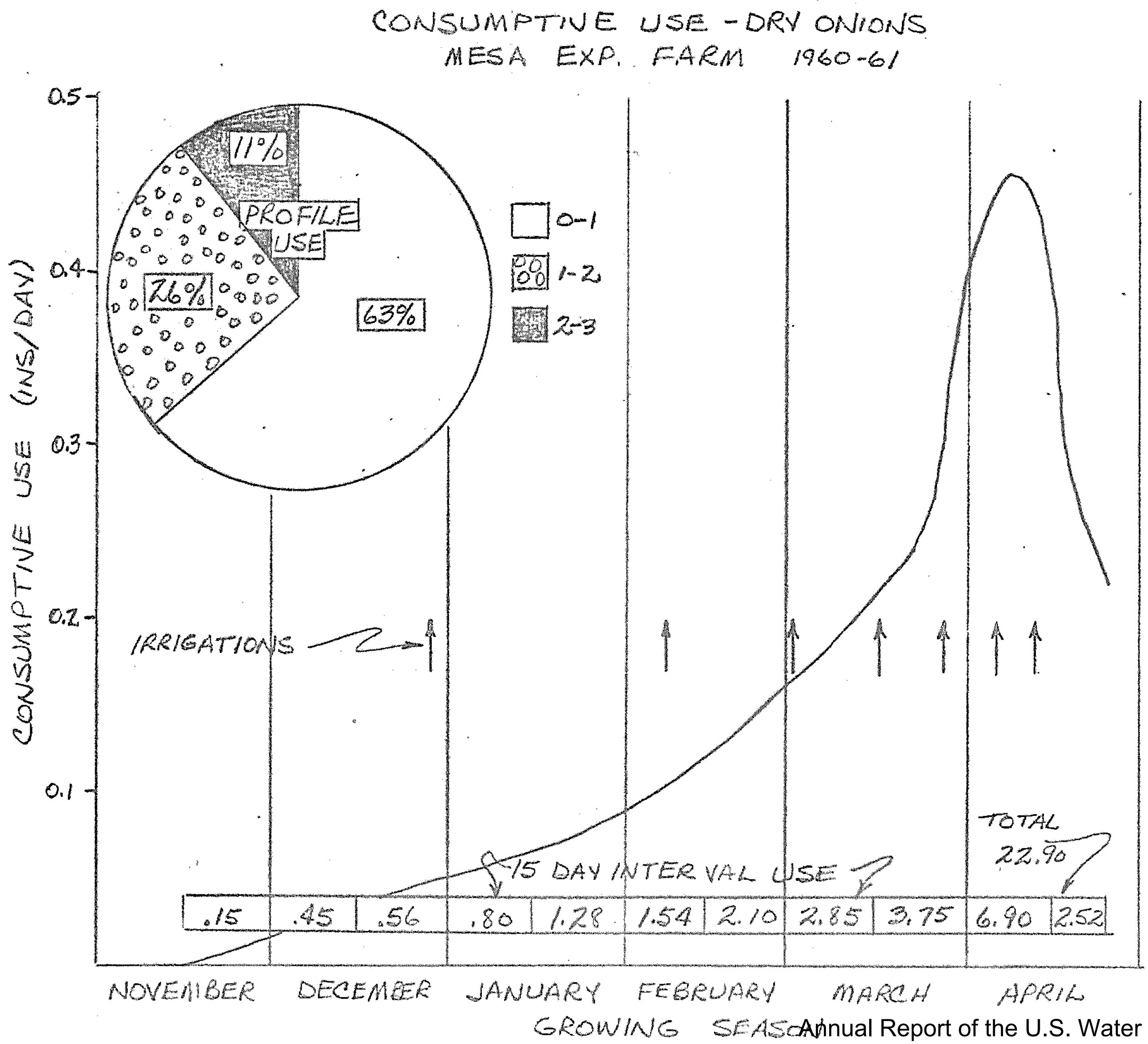
SOIL MOISTURE PERCENTAGE
CARROTS MESA EXP. FARM 1960-61





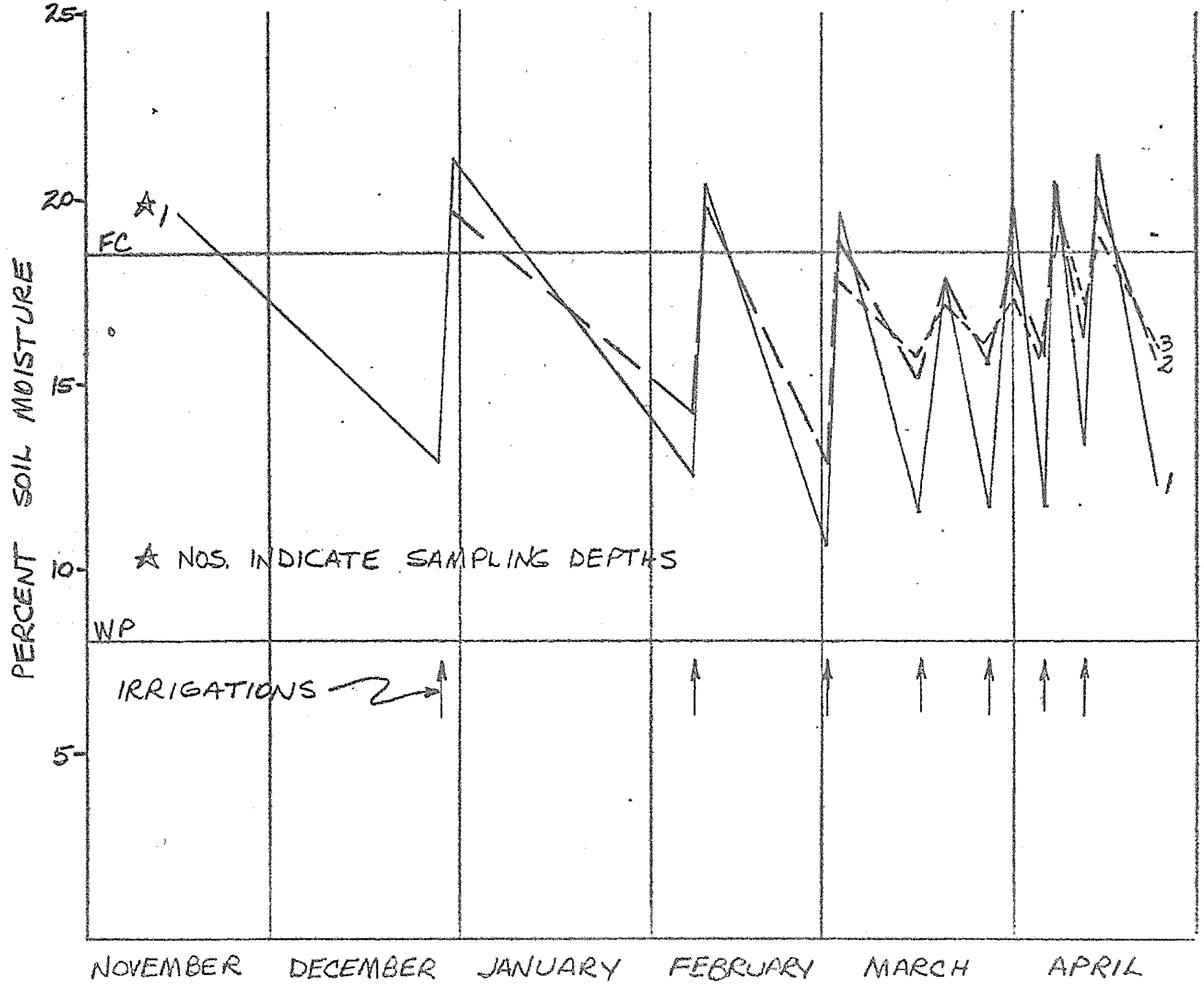
CONSUMPTIVE USE - GREEN ONIONS
MESA EXP. FARM 1960-61
CONSUMPTIVE USE (INS./DAY)
0.5
0.4
0.3
0.2
0.1
6%
10%
PROFILE USE
27%
58%
0-1
1-2
2-3
3-4
IRRIGATIONS
15 DAY INTERVAL USE
TOTAL 23.83
.30
.75
1.04
1.35
1.76
1.82
2.38
3.15
4.48
6.80
NOVEMBER
DECEMBER
JANUARY
FEBRUARY
MARCH
APRIL
GROWING SEASON

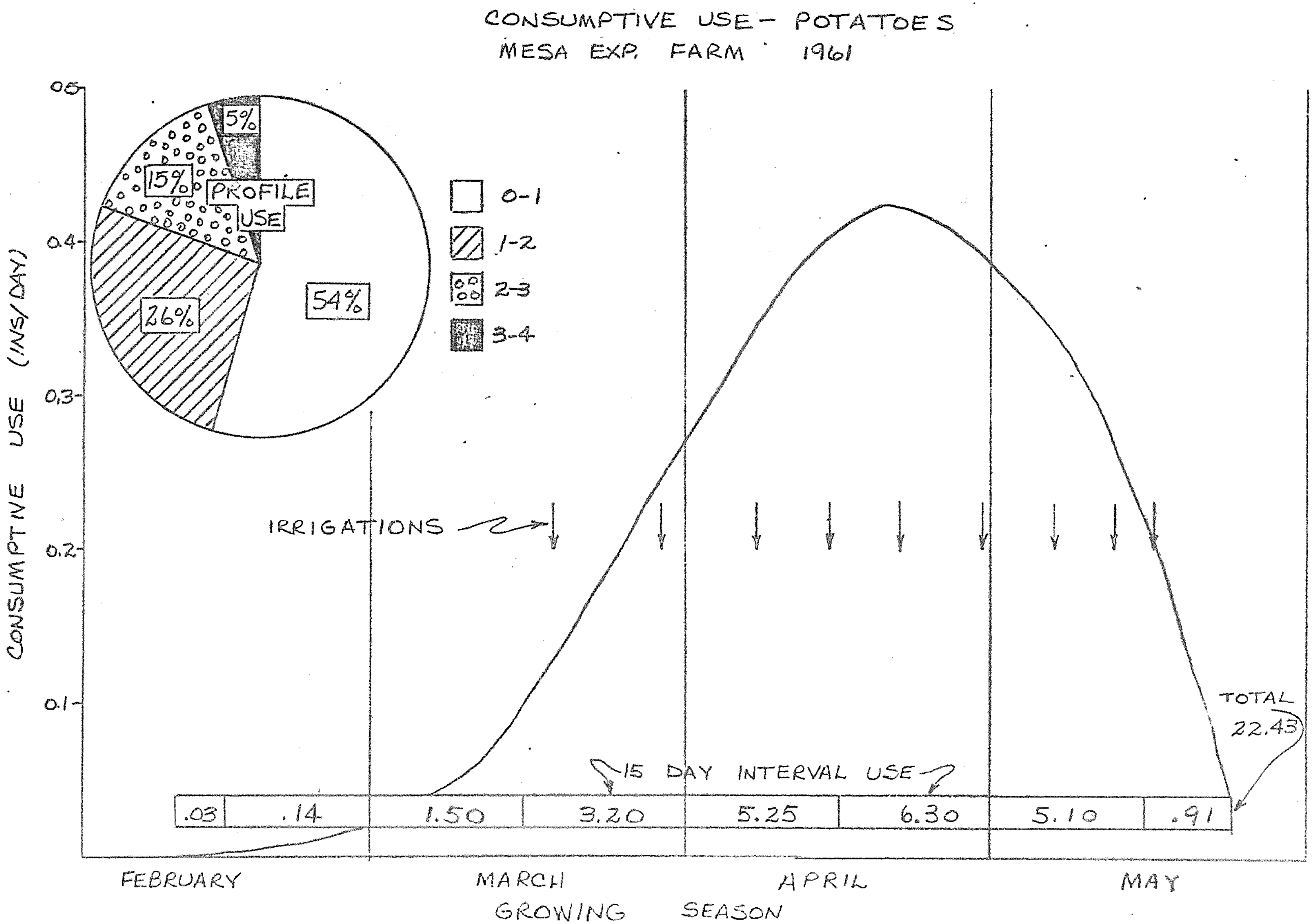

SOIL MOISTURE PERCENTAGE - GREEN ONIONS
MESA EXP. FARM 1960-61
PERCENT SOIL MOISTURE
25
20
15
10
5
FC
WP
★ NOS. INDICATE SAMPLING DEPTHS
IRRIGATIONS
NOVEMBER
DECEMBER
JANUARY
FEBRUARY
MARCH
APRIL
GROWING SEASON

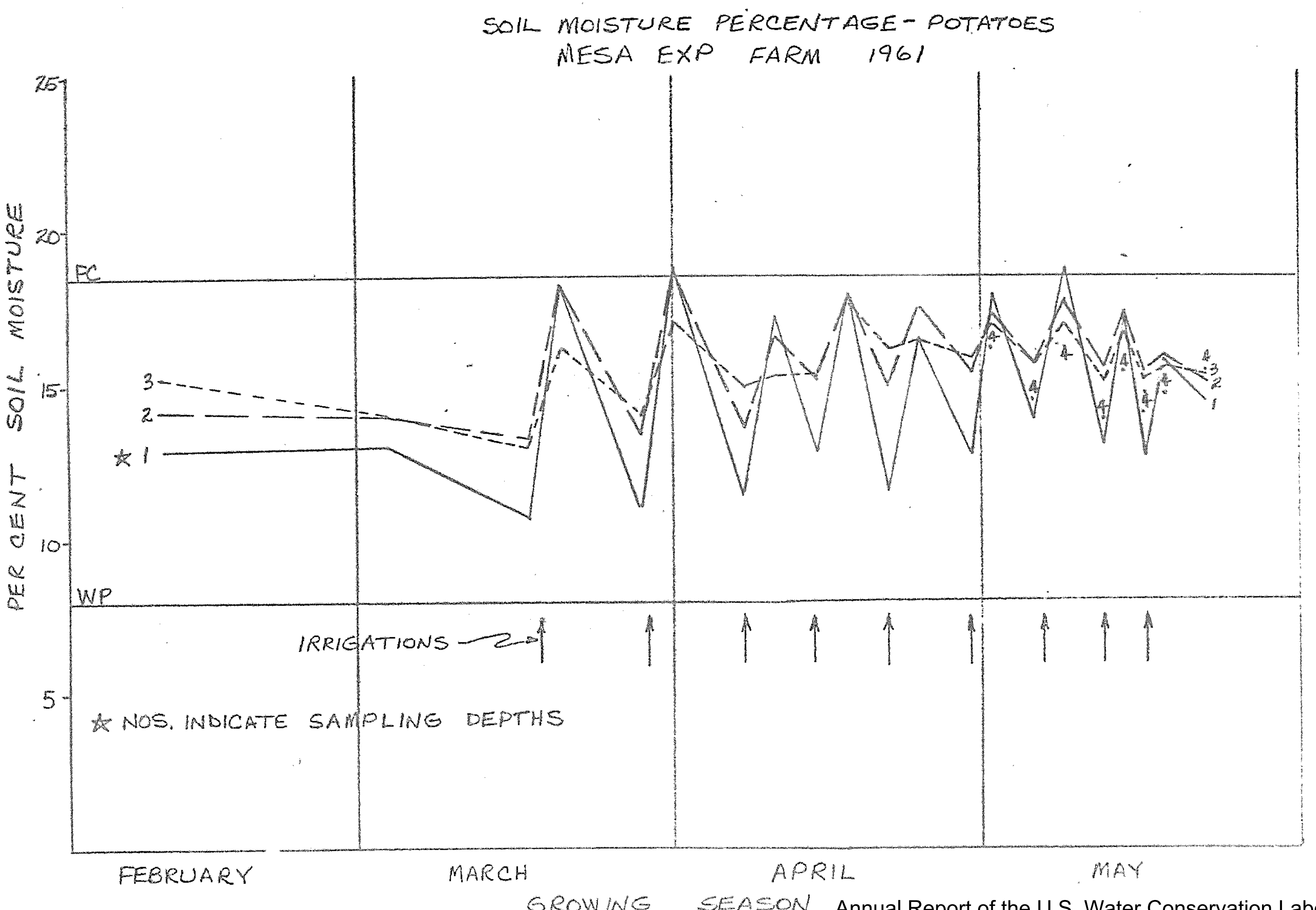


CONSUMPTIVE USE - DRY ONIONS
MESA EXP. FARM 1960-61
CONSUMPTIVE USE (INS/DAY)
0.5
0.4
0.3
0.2
0.1
11%
PROFILE USE
26%
63%
0-1
1-2
2-3
IRRIGATIONS
15 DAY INTERVAL USE
TOTAL 22.90
.15
.45
.56
.80
1.28
1.54
2.10
2.85
3.75
6.90
2.52
NOVEMBER
DECEMBER
JANUARY
FEBRUARY
MARCH
APRIL
GROWING SEASON

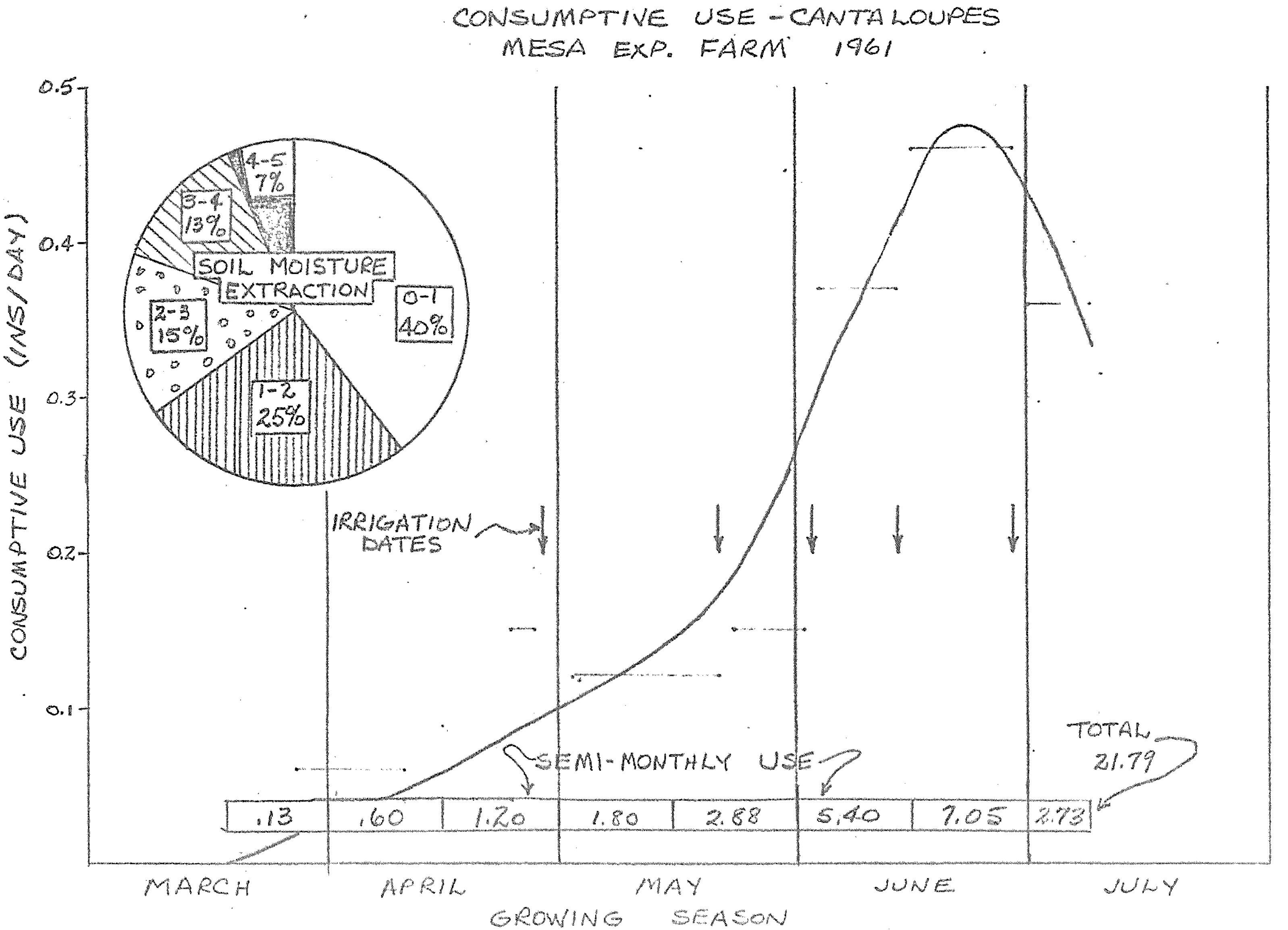
SOIL MOISTURE PERCENTAGE - DRY ONIONS
MESA EXP. FARM 1960-61



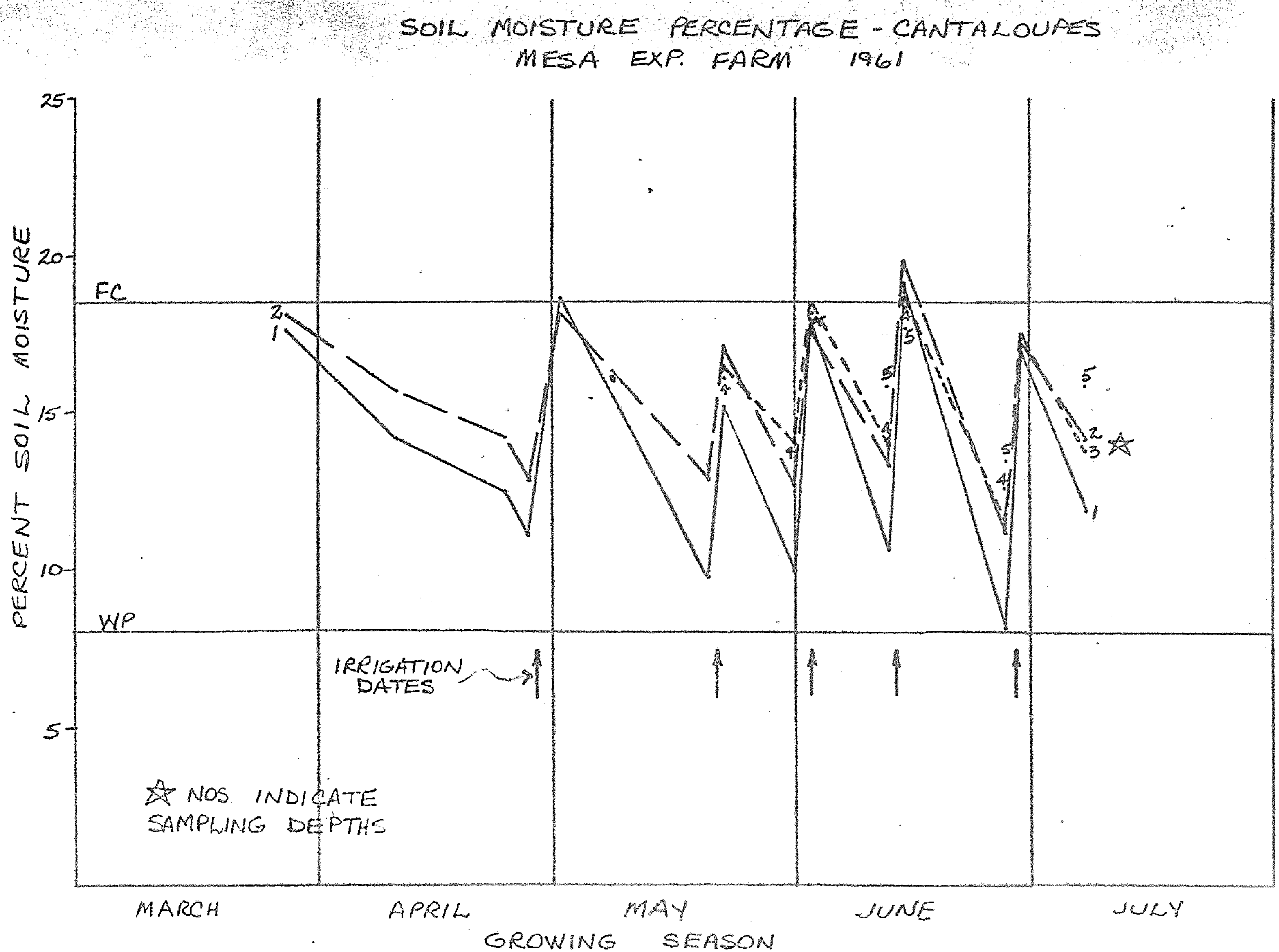

CONSUMPTIVE USE - POTATOES
MESA EXP. FARM 1961
CONSUMPTIVE USE (INS/DAY)
0.5
0.4
0.3
0.2
0.1
5%
15%
PROFILE USE
26%
54%
0-1
1-2
2-3
3-4
IRRIGATIONS
15 DAY INTERVAL USE
.03
.14
1.50
3.20
5.25
6.30
5.10
.91
TOTAL 22.43
FEBRUARY
MARCH
APRIL
MAY
GROWING SEASON



SOIL MOISTURE PERCENTAGE - POTATOES
MESA EXP FARM 1961
PER CENT SOIL MOISTURE
25
20
15
10
5
FC
WP
3
2
★ 1
4
IRRIGATIONS
★ NOS. INDICATE SAMPLING DEPTHS
FEBRUARY
MARCH
APRIL
MAY
GROWING SEASON

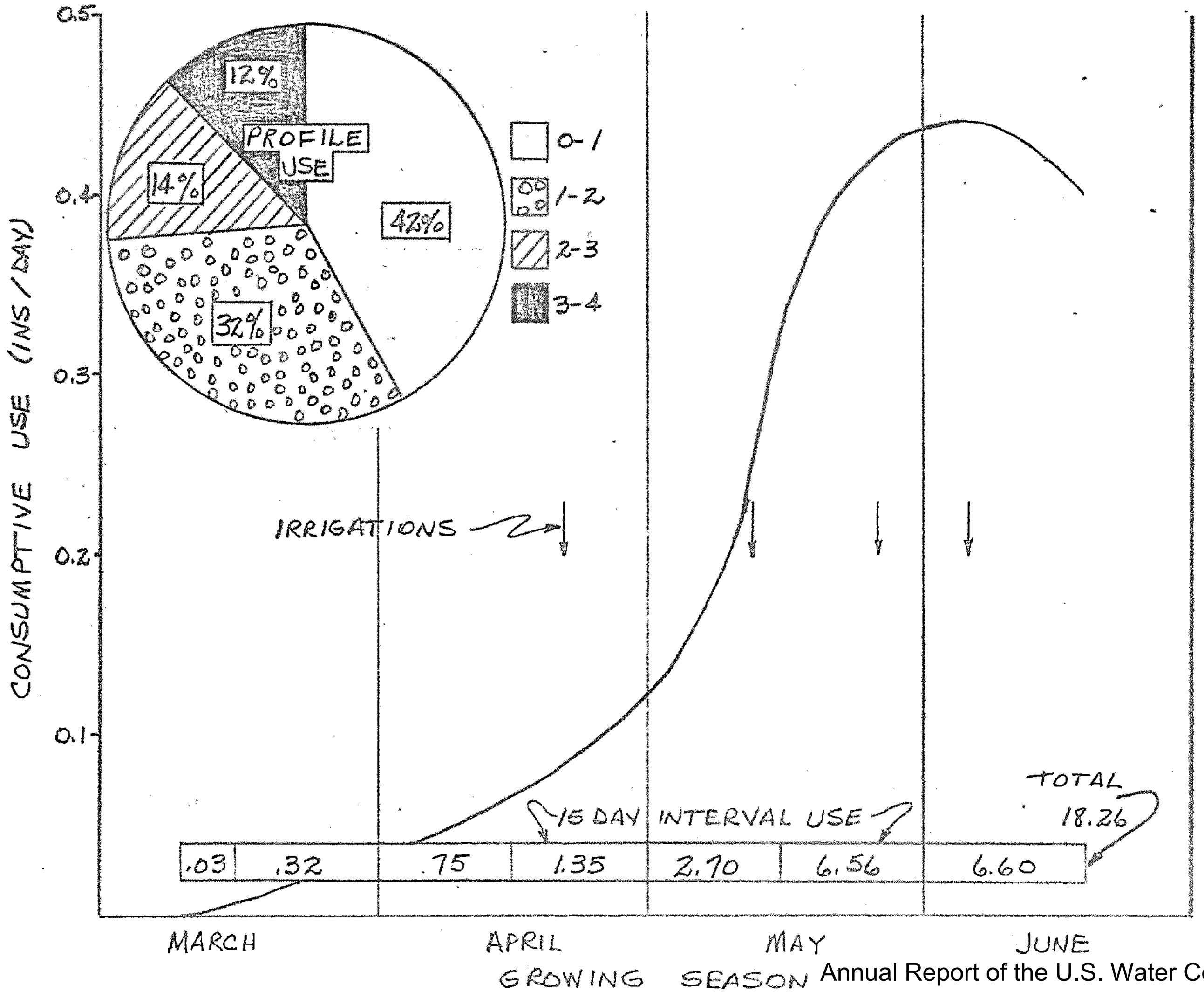


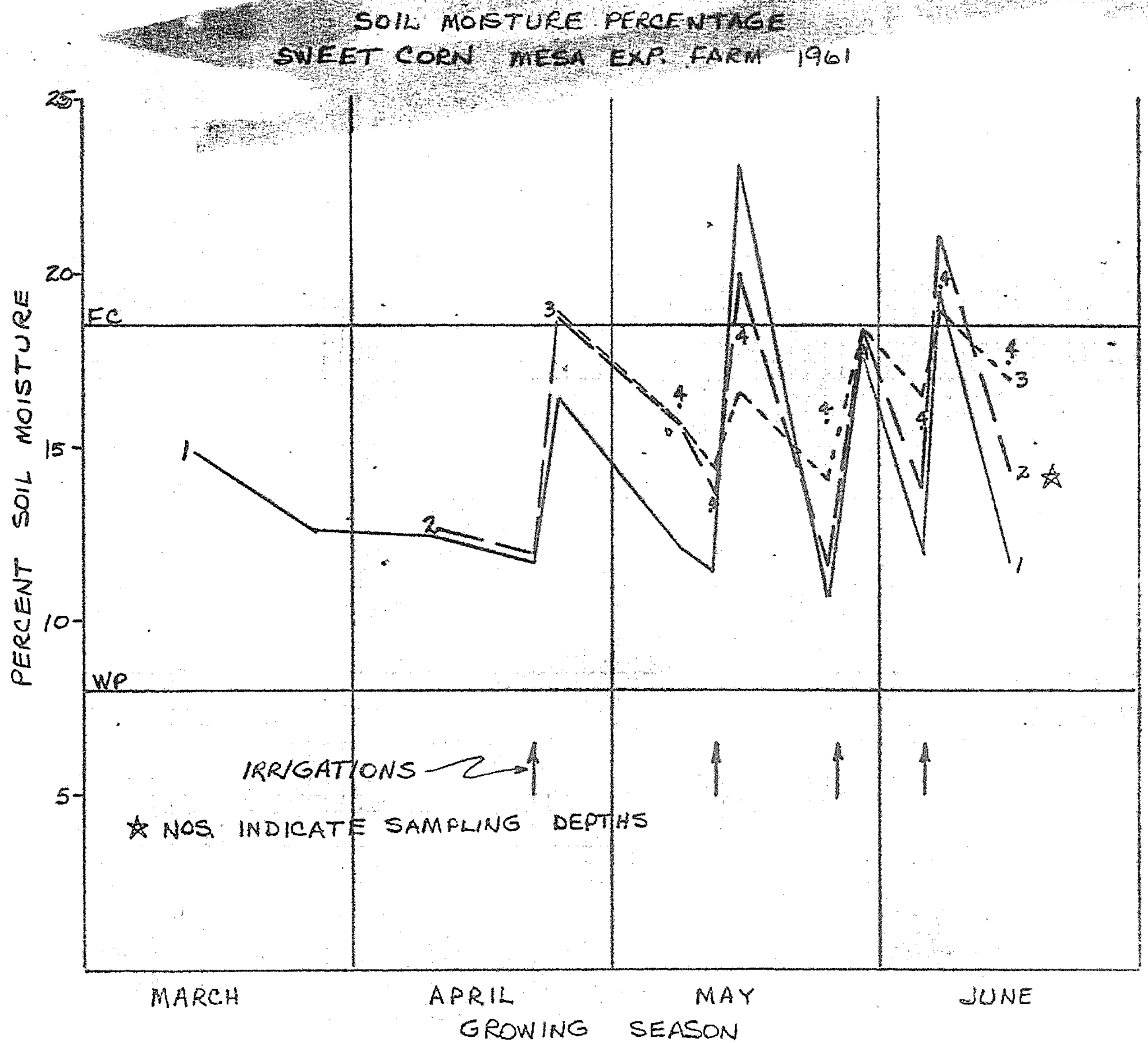
CONSUMPTIVE USE - CANTALOUPES
MESA EXP. FARM 1961
CONSUMPTIVE USE (INS/DAY)
0.5
0.4
0.3
0.2
0.1
SOIL MOISTURE EXTRACTION
0-1 40%
1-2 25%
2-3 15%
3-4 13%
4-5 7%
IRRIGATION DATES
SEMI-MONTHLY USE
.13
.60
1.20
1.80
2.88
5.40
7.05
2.73
TOTAL 21.79
MARCH
APRIL
MAY
JUNE
JULY
GROWING SEASON



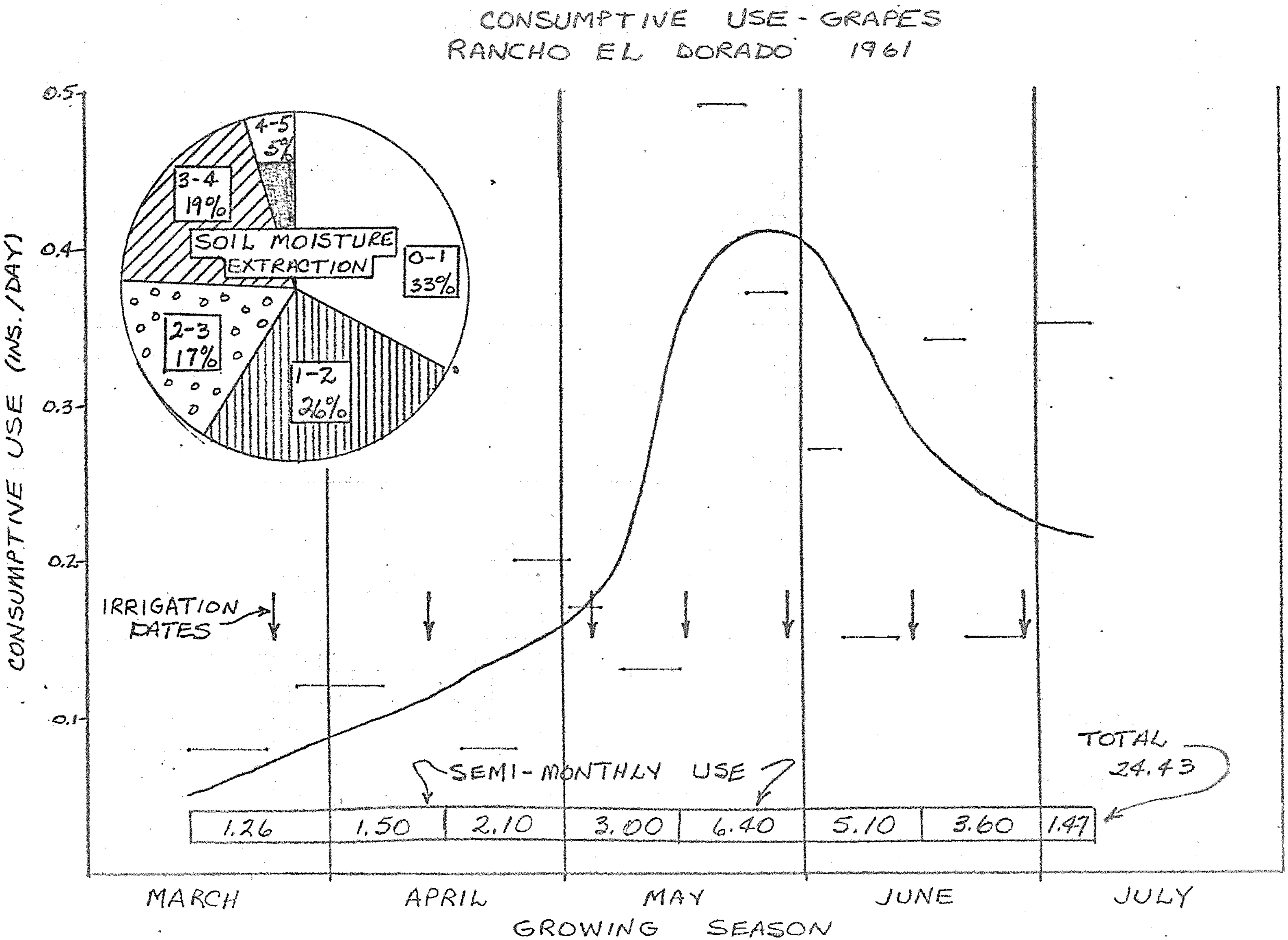
SOIL MOISTURE PERCENTAGE - CANTALOUPES
MESA EXP. FARM 1961
PERCENT SOIL MOISTURE
25
20
15
10
5
FC
WP
IRRIGATION DATES
☆ NOS INDICATE SAMPLING DEPTHS
MARCH
APRIL
MAY
JUNE
JULY
GROWING SEASON

CONSUMPTIVE USE - SWEET CORN
MESA EXP FARM 1961

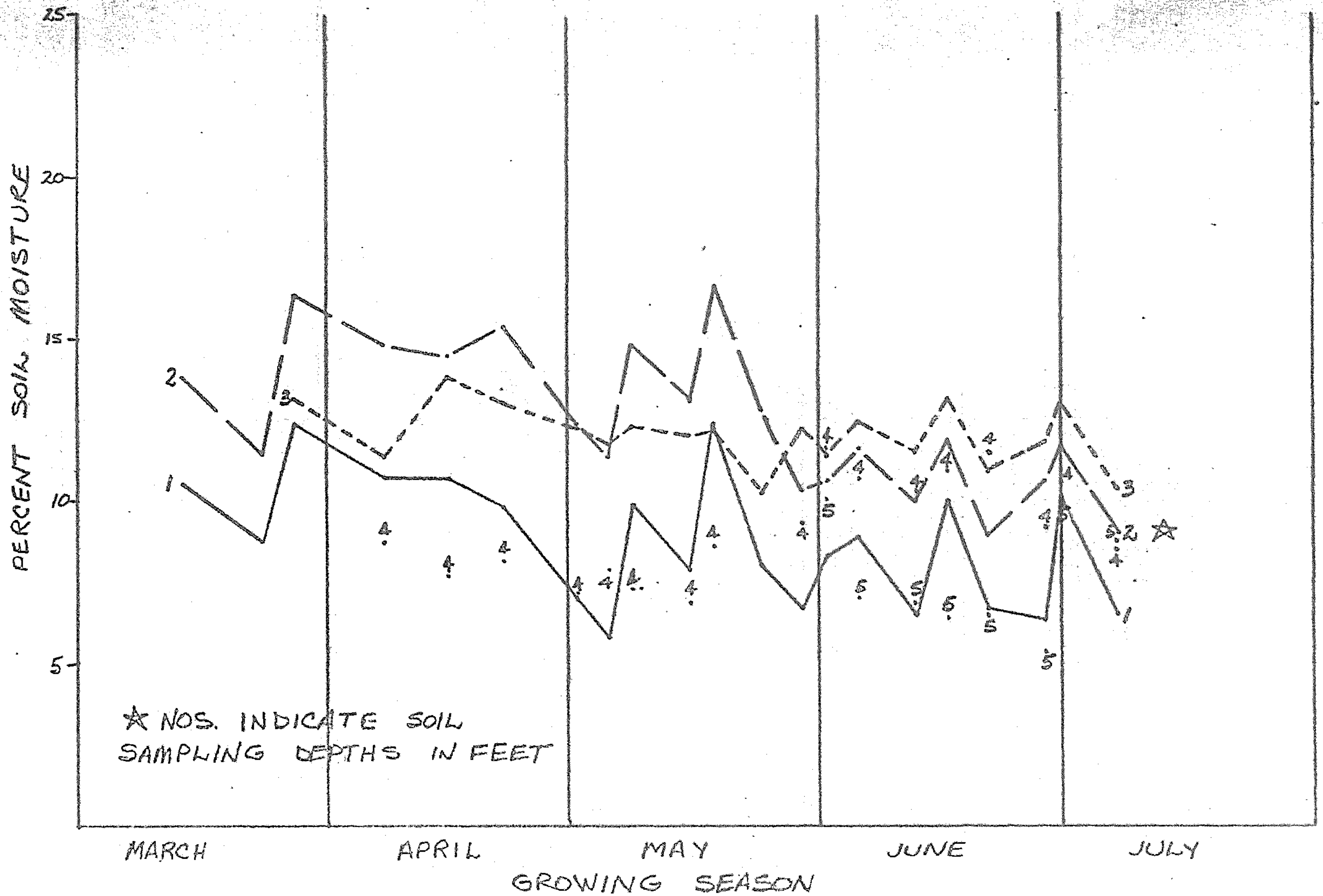


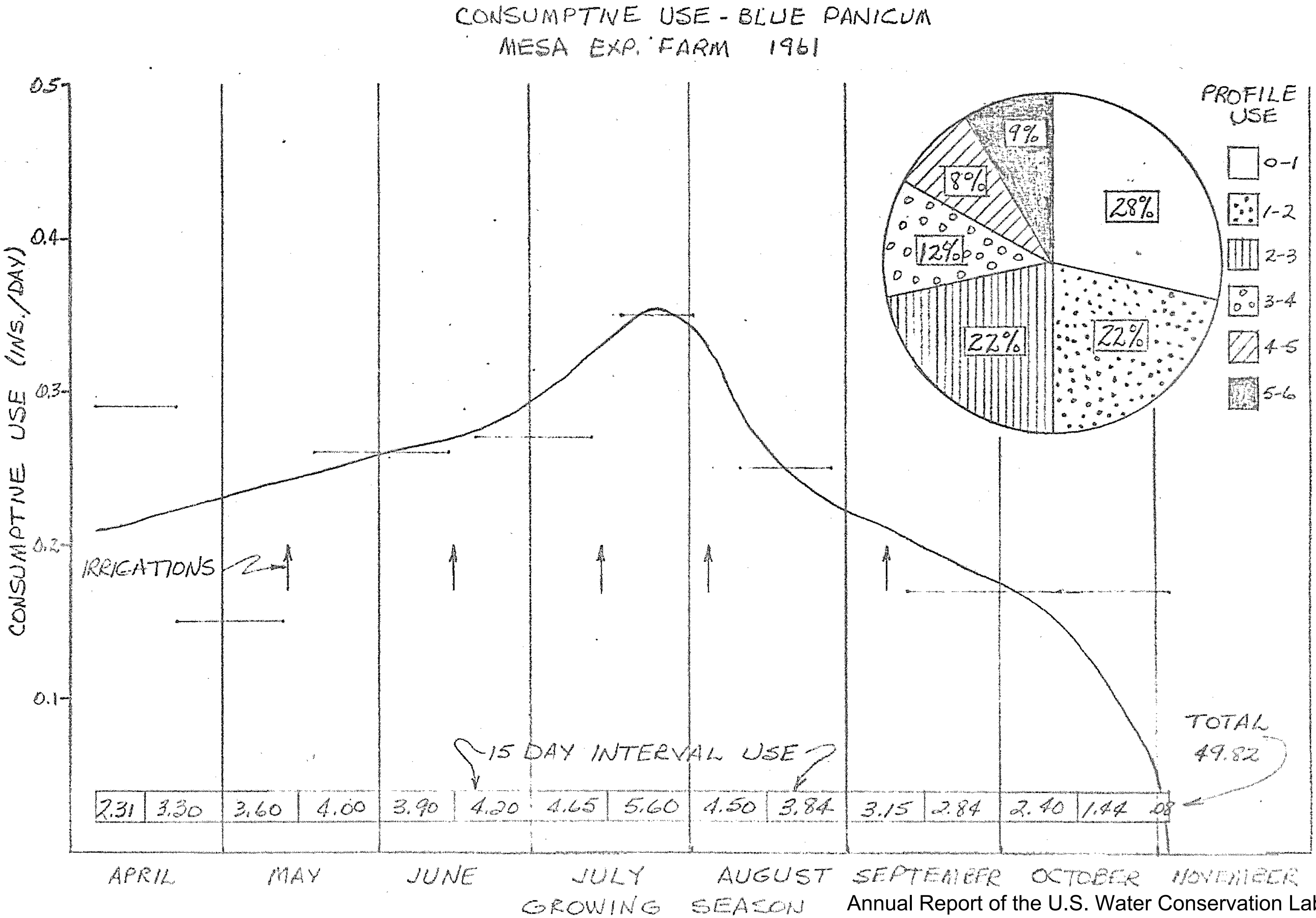


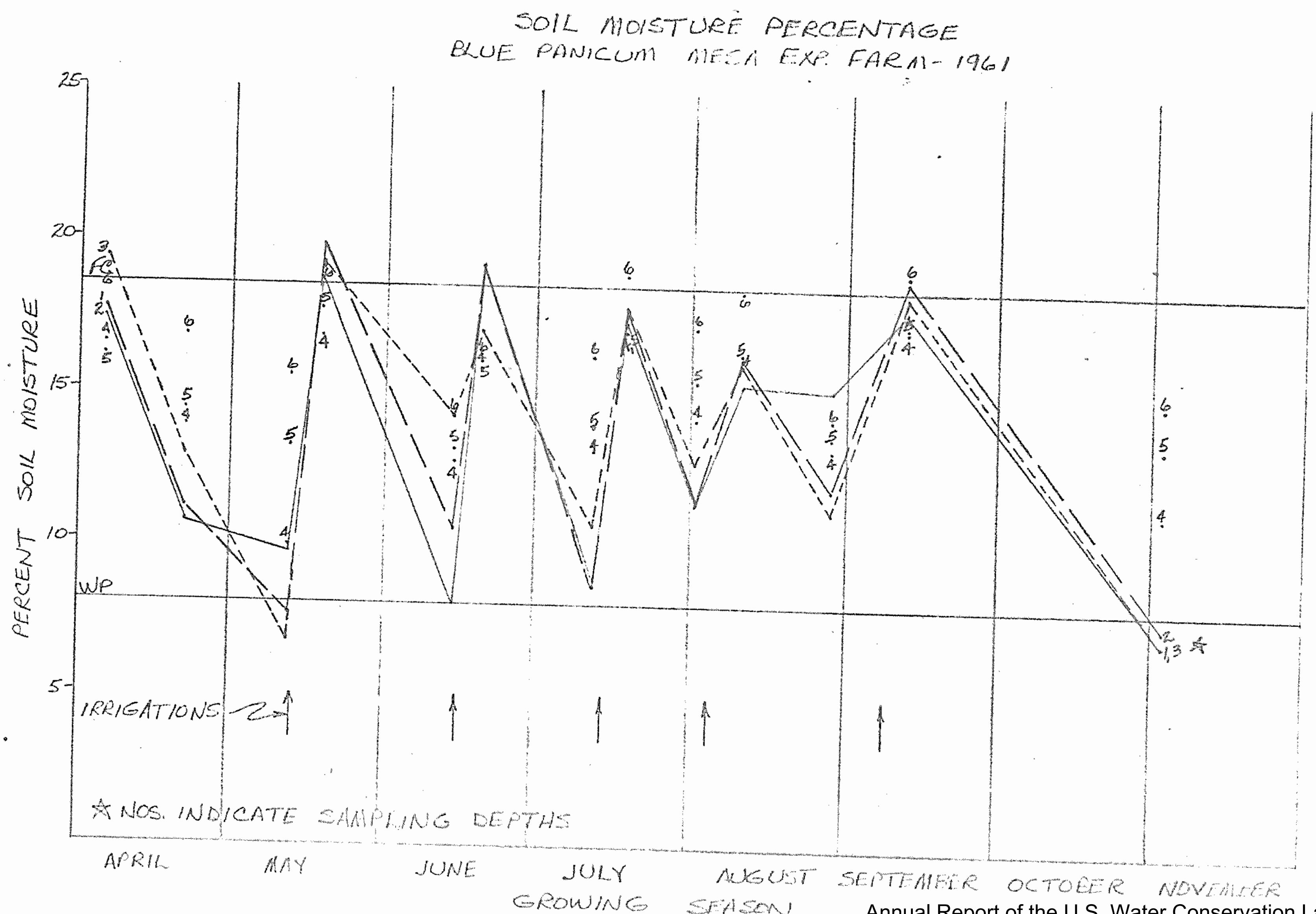
SOIL MOISTURE PERCENTAGE
SWEET CORN MESA EXP. FARM 1961
PERCENT SOIL MOISTURE
25
20
15
10
5
FC
WP
IRRIGATIONS
☆ NOS. INDICATE SAMPLING DEPTHS
MARCH
APRIL
MAY
JUNE
GROWING SEASON


CONSUMPTIVE USE - GRAPES
RANCHO EL DORADO 1961
CONSUMPTIVE USE (INS./DAY)
0.5
0.4
0.3
0.2
0.1
4-5
5%
3-4
19%
SOIL MOISTURE
EXTRACTION
0-1
33%
2-3
17%
1-2
26%
IRRIGATION
DATES
SEMI-MONTHLY USE
TOTAL
24.43
1.26
1.50
2.10
3.00
6.40
5.10
3.60
1.47
MARCH
APRIL
MAY
JUNE
JULY
GROWING SEASON

SOIL MOISTURE PERCENTAGE - GRAPES
RANCHO EL DORADO 1961




CONSUMPTIVE USE - BLUE PANICUM
MESA EXP. FARM 1961
CONSUMPTIVE USE (INS./DAY)
0.5
0.4
0.3
0.2
0.1
IRRIGATIONS
PROFILE USE
0-1
1-2
2-3
3-4
4-5
5-6
28%
22%
22%
12%
8%
9%
15 DAY INTERVAL USE
TOTAL 49.82
2.31
3.30
3.60
4.00
3.90
4.20
4.65
5.60
4.50
3.84
3.15
2.84
2.40
1.44
.08
APRIL
MAY
JUNE
JULY
AUGUST
SEPTEMBER
OCTOBER
NOVEMBER
GROWING SEASON


SOIL MOISTURE PERCENTAGE
BLUE PANICUM MESA EXP. FARM - 1961
PERCENT SOIL MOISTURE
25
20
15
10
5
FC
WP
IRRIGATIONS
☆ NOS. INDICATE SAMPLING DEPTHS
APRIL
MAY
JUNE
JULY
AUGUST
SEPTEMBER
OCTOBER
NOVEMBER
GROWING SEASON

TITLE: ANALYTICAL LABORATORY

PROGRESS:

The work performed by the Analytical Laboratory during 1961 included 575 chemical and physical analyses of 188 soil samples and 428 chemical analyses of 132 water samples. A breakdown of the analyses is given in Table 1.

Table 1.--Analysis performed by Analytical Laboratory 1961.

Analysis	Number of determinations
Particle size	
a. Hydrometer	116
b. Sieve	2
Moisture characteristics	
a. Pressure cooker	150
b. Pressure membrane	190
pH and saturated conductivity	41
Calcium and magnesium	358
Sodium and potassium	82
Carbonate and bicarbonate	24
Chloride and sulfate	32
Cation exchange capacity	6
Surface area	2

A list of chemical and physical procedures checked adopted for use by the Analytical Laboratory was given in the 1960 Annual Report.

PERSONNEL:

The position of Analytical Laboratory Technician was held by three persons during 1961. A. J. Frasier resigned 2/8/61. Ben Albert held the position from 1/23/61 to 7/22/61. J. Bennett Miller replaced Albert on 7/14/61 and has remained in that position.

Report prepared by: J. Bennett Miller, F. S. Nakayama, Ray D. Jackson.

PAPERS PREPARED OR PUBLISHED DURING 1961

	Laboratory MS No.
1. Biddulph, O., Nakayama, F. S., and Cory, R. The transpiration stream and the ascension of calcium. Plant Physiol. 36:429-436. 1961.	28
2. Bouwer, Herman. Analyzing ground-water mounds by resistance network. J. Irrig. and Drain. Div., Proc. Am. Soc. Civil Eng. (In press).	42
3. Bouwer, Herman. Application of the double-tube method for field measurement of hydraulic conductivity of soil above the water table. Trans. Am. Soc. Agr. Eng. (In press).	53
4. Bouwer, Herman. A double tube method for measuring hydraulic conductivity of soil in situ above a water table. Soil Sci. Soc. Am. Proc. 25:334-339. Sept.-Oct., 1961.	22
5. Bouwer, Herman, Myers, L. E., and Rice, R. C. Effect of velocity on seepage and its measurement. J. Irrig. and Drain. Div., Proc. Am. Soc. Civil Eng.	57
6. Bouwer, Herman. Field determination of hydraulic conductivity above a water table with the double-tube method. Soil Sci. Soc. Am. Proc. (In press).	41
7. Bouwer, Herman. Measuring soil permeability above a water table and analyzing ground-water mound behavior with a resistance network analog. Ground-water Recharge Conf. Proc., Berkeley, California. (In press).	43
8. Bouwer, Herman. Research at the U. S. Water Conservation Laboratory, Tempe, Arizona. 15th Ann. Nevada Water Conf. Proc., Carson City, Nevada. Sept. 1961; pp. 38-41.	49
9. Bouwer, Herman. A variable head technique for seepage meters. J. Irrig. and Drain. Div., Proc. Am. Soc. Civil Eng. 87 IR 1:31-44. 1961.	17
10. Clark, Francis E., Jackson, Ray D., and Gardner, Herbert R. Measurement of microbial thermogenesis in soil. Soil Sci. Soc. Am. Proc. (In press).	38
11. Denmead, O. T., Fritschen, L. J., and Shaw, R. H. Net radiation measurements in hill planted corn. Agr. J. (In press).	37

		Laboratory MS No.
12.	Dennis, R. E., et al, and Erie, L. J. Alfalfa in Arizona. Arizona Agr. Ext. Ser. Bull. A-16. 1961.	15
13.	Erie, Leonard J. Evaluation of infiltration measurements. Agr. Eng. (In press).	20
14.	Erie, Leonard J. Closing the irrigation gap. The Cotton Trade J. Intern. Ed., 1961-1962; pp. 82, 234-235.	47
15.	Fritschen, Leo J. Construction and evaluation of a miniature net radiometer. J. Applied Meteorol. (In press).	50
16.	Jackson, Ray D., and Taylor, Sterling A. Heat transfer. Am. Soc. Agron. Monograph, "Methods of Soil Analysis". (In press).	33
17.	Jackson, R. D., Reginato, R. J., and Reeves, W. E. A mechanized device for packing soil columns. USDA-ARS Ser. Bull. 41-52. (In press).	54
18.	Jackson, R. D., Reginato, R. J., and Reeves, W. E. A mechanized soil column packer. Soil Sci. Soc. Am. Proc. (In press).	55
19.	Myers, Lloyd E. Potential low cost treatments to reduce seepage losses. Soil Conserv. (In press).	52
20.	Myers, Lloyd E. Waterproofing soil to collect precipitation. J. Soil and Water Conserv. 16:281-282. 1961.	46
21.	Nakayama, F. S., and Scott, A. D. Gas sorption by soils and clay minerals: I. Dissolution of oxygen in moist materials. Soil Sci. (In press).	44
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